COMBUSTION

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The Physical Characteristics of Natural Draft Chimneys
By J. G. MINGLE

Liquefaction of Gaseous Mixtures
By WM. L. DeBAUFRE

OTHER ARTICLES IN THIS ISSUE BY
WM. A. BONE • DAVID BROWNLIE • HENRY KREISINGER • JOSEPH BRESLOVE • B. J. CROSS

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VOLUME TWO • NUMBER TEN

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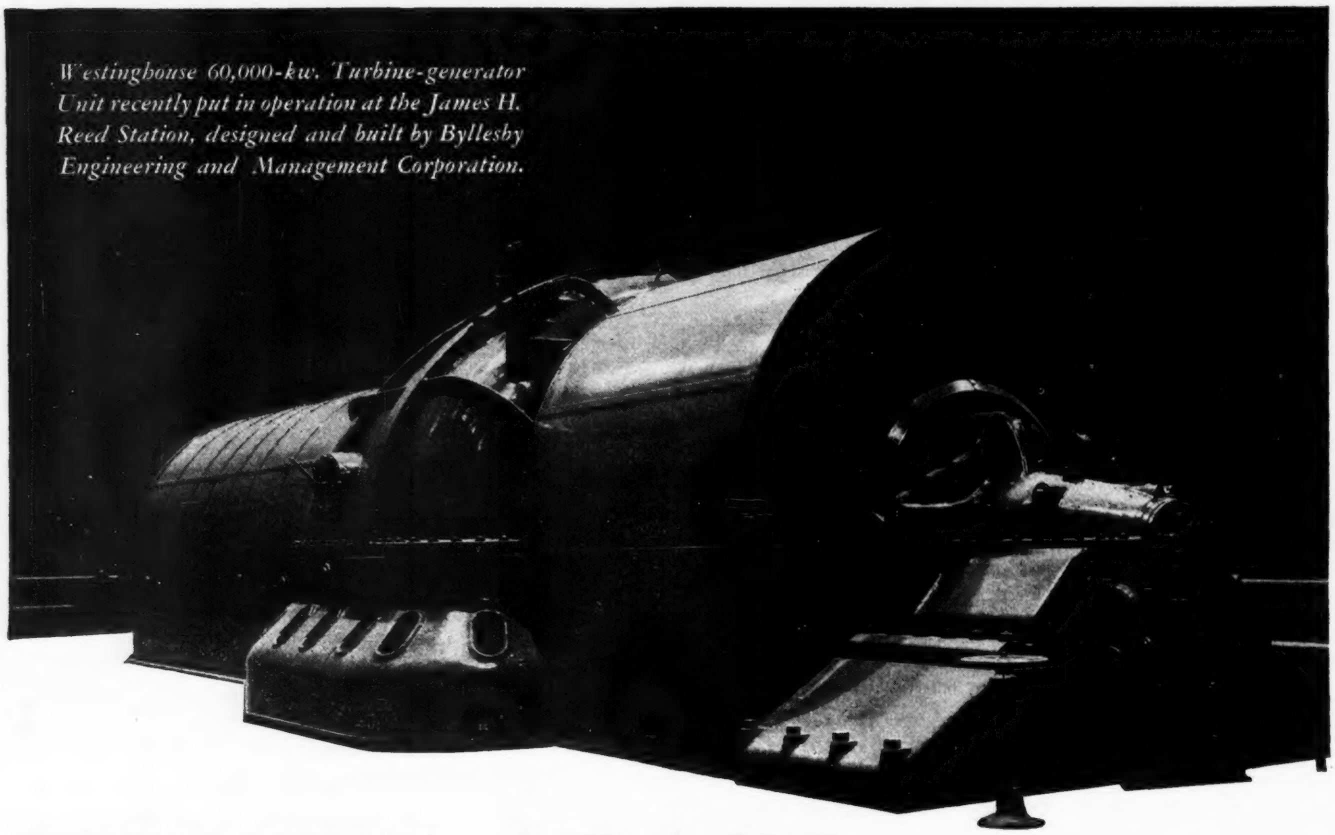

Westinghouse 60,000-kw. Turbine-generator Unit recently put in operation at the James H. Reed Station, designed and built by Byllesby Engineering and Management Corporation.

CHOSEN AGAIN

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WITH the starting up of the new James H. Reed Station in Pittsburgh, the Duquesne Light Company put into service another Westinghouse Turbine-generator Unit.

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COMBUSTION

VOLUME 2 APRIL 1931 NUMBER 10

Engineering Administration

KARL T. COMPTON

AS THE result of meeting large numbers of engineering graduates during the past year, I have been impressed above all by two salient facts: first, a surprisingly large proportion of these men are occupying positions of really major importance; second, these positions are to a surprisingly large extent administrative positions, often with very little relationship to the particular branch of engineering studied in college.

A notable illustration is found in Mr. Gerard's much discussed list of the men who control the economic destiny of America. If this list be divided into engineering college graduates, other college graduates and non-college men, it is found that the engineering college graduates have by far the largest proportional representation.

I recently heard significant remarks from presidents and directors of three of the largest industrial organizations in the world. One said that in his company careful personnel study had shown that men trained in the physical sciences most quickly and successfully advanced into executive positions. The others agreed that in their organizations the "ceiling" of administrative achievement had proved to be higher for men trained as engineers than for others.

An interesting analysis of "What Engineers Become," proving the pronounced trend toward executive leadership, is to be found in an article by Professor Erwin H. Schell in The Technology Review, XXXII, March, 1930. It is shown, for example, that 38 per cent of engineers, seven years out of college, are already in administrative positions.

Such facts would seem to justify either or both of the following conclusions:

(1) An engineering training is an excellent training for a successful administrative career. This may be on account of the habits of orderly thought, systematic analysis of situations, concentration upon realities, quantitative checking of theories by experience, which are essential attributes of the engineer.

(2) The type of young men to whom engineering appeals as a profession is often the type naturally well fitted for administrative success. Men of this type like to figure out ways of doing things and, when a satisfactory plan is found, cannot restrain themselves from putting the plan into operation.

This situation would seem to indicate the advantages to be gained by including more study of economics and business principles in the curriculum of engineering schools,—not with the thought that such courses *make* great business men, but rather that a background of economic principles and knowledge of business practices in such matters as accounting, marketing, organization, etc., should strengthen the engineer for handling the administrative duties which experience shows are likely to come his way. This point of view is well supported by the experience of more than a thousand graduates of a course in Business and Engineering Administration, which has been carried on at the Massachusetts Institute of Technology since 1914, and which purposes to give a business training based on an engineering background.

The important thing to remember is that "the engineer who accepts responsibilities of management, must put to practical use the products of the social as well as the physical sciences," and should profit by training in both.

Karl T. Compton

President
Massachusetts Institute of Technology

EDITORIAL

This Age of Giants

THE achievements of yesterday are but commonplace today.

The Bremen and Europa, hailed as marvels of marine architecture but a few months ago, are now accepted as but part of an increasingly efficient transatlantic service.

Countless thousands of blasé New Yorkers pass the Empire State Building each day without so much as a glance skyward toward the great mooring mast for dirigibles atop this tallest structure ever built by man—rising 1253 feet above the street level.

A little over a year ago, the first of the giant boiler units, each guaranteed to produce 800,000 lb. of steam per hour, was placed in service at the East River Station of the New York Edison Company. These units have since operated at capacities of more than 1,250,000 lb.

Two units at Hell Gate have produced steam at the rate of 1,000,000 lb. per hour.

The fifth unit at the Kips Bay Station of the New York Steam Corporation has topped 1,000,000 lb.

The two new 1400 lb. pressure boilers at the Fordson Plant of the Ford Motor Company were designed for 800,000 lb. per hour and it is quite likely that these units will produce at rates over 1,000,000 lb. shortly after they are "on the line."

We grant that these boilers of the 1,000,000 lb. class are large boilers—Calvin Coolidge is said to have once remarked that "a million is a lot of anything"—but we are living in an age of giants and familiarity with "big things" has created a tendency to take "big things" for granted.

We have lost our appreciation because we have lost our perspective. The following comparisons are offered to serve as yard-sticks by which the tremendous capacities of these super-boilers may be measured and better understood.

At a rating of 1,250,000 lb. of steam per hour, one of the boilers at the East River Station, New York Edison Company:

Could supply steam enough to generate 120,000 kw. of electrical energy,—sufficient to serve the entire city of Washington, D. C.

Could develop 160,000 brake hp.—sufficient to drive two ships the size of the Aquitania with sufficient power left over to run two smaller liners.

Could furnish enough steam to operate thirty-two 20th Century Limited trains.

Could furnish enough power to lift the Empire State Building its own height in six hours.

Requires about 60 tons of coal per hour, 29 carloads a day, over a half million tons a year—enough to furnish heat to a city of 200,000.

Requires over 3,600,000 gallons of water a day—enough to serve a community of 60,000 people.

Yet these large boilers are of conservative and rational design. Ample factors of safety have been strictly maintained. There is no sacrifice in efficiency or dependableness. In fact, high economies and extreme reliability are characteristic of these large units. Space is conserved and capital and operating costs are at a minimum.

They are giants indeed, these boilers—the first of a race of giants who are destined in the near future to supplant, in large measure, the pigmies of the past.

Blind Flying

ONE of the most recent and spectacular developments in aviation is blind flying in which the aviator takes off, orientates his plane, follows a straight-line route to his destination and effects a clean, three-point landing without so much as a glance beyond the walls of his closed cockpit.

Hazardous as it may seem, blind flying represents a distinct advancement toward safe flying, for blind flying is controlled flying, dependent upon instruments which definitely remove the factor which has been responsible for the vast majority of crack-ups—the human element.

There's another kind of "blind flying" existent in many steam plants today—the blind operation which results from the lack of instruments and automatic control.

Human judgment applied to estimating temperatures, adjusting feeds and maintaining pressures, is a pitiful misapplication of brains and man power.

Blind flying in aviation represents progress.

Blind operation in the steam plant indicates the failure to keep pace with progress.

Central station steam costs are rapidly approaching the minimum because central station steam plants are largely instrument equipped and instrument controlled. However, industrial plants show average steam costs far above those of the public utility stations and one of the principal reasons for this difference is the woeful lack of adequate instrument and mechanical control in the industrial field.

The steam plant operator is eager to "put his shoulder to the wheel" in improving steam generating economy but his loyalty, willingness and application are largely wasted unless adequate instruments and equipment are available to tell him which way the wheel needs turning.

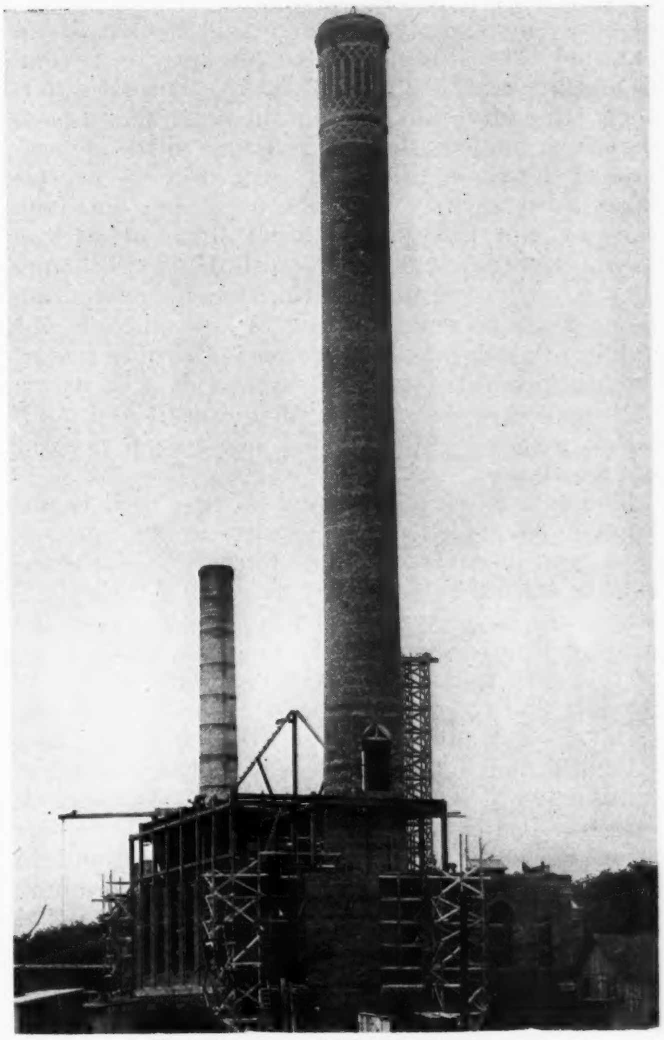
The remedy is up to the plant executive.

The Physical Characteristics of Natural Draft Chimneys*

PART ONE

By J. G. MINGLE
Indianapolis, Ind.

Mr. Mingle's discussion of natural draft chimneys will be published in two parts, of which the accompanying article is Part I. Here the author outlines briefly the history of chimneys and explains the principles of draft. He then discusses the construction and physical characteristics of brick chimneys of both the common brick and perforated radial brick types. The latter type has largely succeeded the former and consequently more space is given to the author's consideration of its characteristics and advantages . . . The second part of this article will be devoted to steel and reinforced concrete chimneys.



Typical large radial brick chimney

CHIMNEYS, in general, may be classified into two general types according to the manner in which they assist in the creation of draft, viz:

1. Natural draft chimneys.
2. Venturi chimneys.

A natural draft chimney, with the assistance of a thermal difference, creates draft by means of an aspiration while a venturi chimney with the assistance of a small blower creates draft by means of an induction as the result of the gases discharging into a constricted orifice. Both types of chimney, in short, assist in the creation of a type of draft by suction as contrasted with forced draft which is a type of draft by blowing, the difference between the two being in the manner in which each is created.

A natural draft chimney is used as a draft producer either by itself alone or in conjunction with some form of mechanical draft producing apparatus. It is one of the most important parts of the entire plant yet the function it plays in the generation of power and in the efficient operation of the steam plant is but little understood. The chimney may be regarded as the lungs of the plant just as the boiler may be regarded as the digestive apparatus and the boiler feed pump, the heart, of the plant. By assisting in the production of draft, the chimney supplies the impulsive action necessary for the flow of the gases throughout the entire installation.

Until a few years ago, a natural draft chimney was almost the sole producer of draft used in steam plants. Of late years, however, the various systems of mechanical draft have been adopted quite extensively. Today, particularly in the larger size plants, a natural draft chimney is almost invariably used in connection with some form of mechanical draft producing apparatus, either in conjunction with, or as an adjunct to, the system.

A natural draft chimney performs the two-fold service of assisting in the creation of draft by aspiration and also of discharging the gases at an elevation sufficient to prevent them from becom-

ing a nuisance. Hence, the duties of a natural draft chimney may be summarized as follows:

1. Draft creation,
2. Gas disposal.

The draft as created by a natural draft chimney is a type of draft by aspiration, or suction, and is the result of a pressure difference, or a head, produced by the difference in weight between the relatively hot gases inside the chimney and a column of atmosphere equivalent in height to that of the chimney. The chimney is the pressure transformer and the draft is the result of the thermal difference. In addition to creating the draft which feeds the air to the fires thereby assisting in the generation of the gases, a natural draft chimney accepts these gases as they leave the breeching and then elevates and finally discharges them at such a height that they will become well dissipated before they reach the ground again, thereby preventing them from becoming a general nuisance to the public. A natural draft system is the only one of the four general systems of draft production which both assists in the creation of the draft and completely disposes of the gases in one operation without assistance.

The date when chimneys were first used is unknown. No evidences of their use by the ancients have been discovered either in archeological excavations or in the deciphered remains of their literature. So far as we are able to discover, even the Ancient Romans and Greeks made no general use of this very important structure, doubtless due to the fact that they had no pressing need for it. In spite of their advanced stage of civilization, they evidently had not discovered, or made themselves familiar with, the principle of draft. The earliest evidence of a chimney structure discovered to date is an ancient mosaic (date unknown) found in Algeria which has on one side a dais of a chimney; nothing has been learned about it other than that it was made long before the Christian Era.

Chimneys were apparently first used in connection with early forges and crude furnaces. Someone observed that a tall hollow structure connected with a forge, or a furnace, helped to make the fire burn briskly and the principle of draft was then discovered and applied. The phenomena may even have been noticed when a fire was built in a hollow tree. The first chimneys were doubtless used as a matter of means and not as a necessity.

The early chimneys were built of common "mud" brick and doubtless were very crude structures. As time went by and the principle of the chimney and draft became better understood, the builders became more experienced and as a result more substantial structures were built. Some of these early chimneys were exceptionally well built as is attested to by the fact that several of them are still standing and their material condition appears to be practically as good as that of the more recently constructed ones. Early chimney theory was very meagre and there was no attempt at proper proportioning or economical design.

The modern chimney seems to have been developed along with modern industry. Its extended use followed closely the introduction and use of the steam boiler. All of the early chimneys were built of common brick. Later on when steel plate was manufactured and the industry became well developed, small guyed steel stacks were built and used. As the size of the boiler increased, larger chimneys were demanded and self-supporting steel chimneys then were used in the larger installations.

Large common brick chimneys were also used but their relative cost was considerably more than that of steel and the use of the brick type became increasingly limited. As a result of this condition, the perforated radial brick type was originated and built. This type of chimney answered the same purpose as that of the common brick type but the material was cheaper in price and the labor cost of erection was considerably less.

Soon after reinforced concrete came into use as a material of construction, chimneys of this material were built. The growth of this type of chimney was relatively slow at first but as the builders became more experienced increased numbers of them were built.

At the present time, the majority of chimneys built are of the radial brick and reinforced concrete types. Steel chimneys are still built to some extent but their use is usually confined to special installations where the use of either one of the other two types is impossible or prohibitive.

Natural draft chimneys may be classified into three general types according to the material used in their construction, viz:

1. Brick
   a. Common
   b. Perforated Radial
2. Steel
   a. Guyed
   b. Self-supporting
3. Reinforced Concrete.

Brick Chimneys

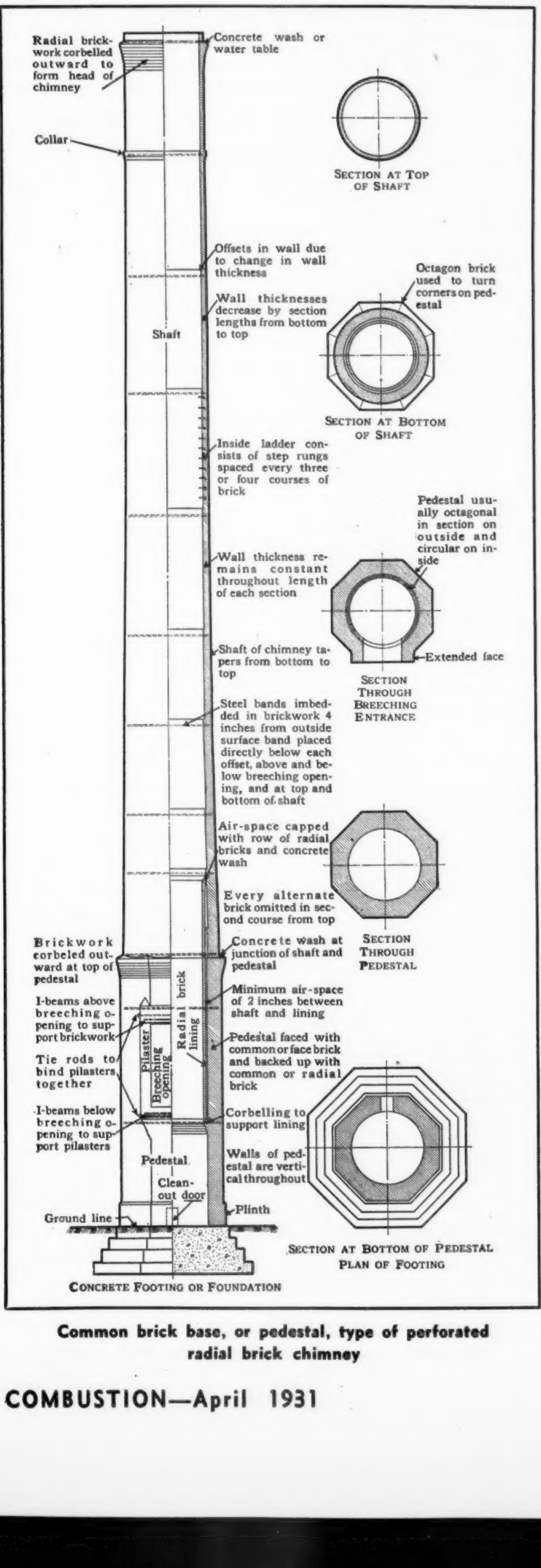
Brick chimneys may be classified into two general types according to the kind of material used in their construction, viz: common brick chimneys and radial brick chimneys.

Common brick chimneys are built of ordinary common brick and radial brick chimneys of a special type of brick called the perforated radial chimney brick, or block. Practically speaking, there is no essential difference between the two types except the material used in their construction, and either type may be used in place of the other. However, owing to their greater relative cost, chimneys of the common brick type are now seldom built and then only in instances where, for some reason, the cost is less than that of the radial brick type.

The basis of the radial brick chimney is the perforated radial brick, or block. The blocks are ordinarily manufactured in five different lengths, viz: 4, 6, 7, 8 and 10 in. Each size has the same face dimensions, the width ranging between 6½ and 7 in. and the height between 4½ and 5 in.

The dimensions of the side opposite the face vary according to the size. The blocks have the shape of a sector of a hollow circle, both the face and the back having slightly curved surfaces. The required wall thicknesses throughout the shaft are built of various combinations of the five different lengths.

The blocks have vertical perforations, or cells, the size and number depending upon the size of the block. Each cell usually averages about one square inch in area. As ordinarily designed, the webs and flanges of each block are made from 1 to 1¼ in. in thickness, the area of each cell then coming as it may without any definite size. The purposes of the cells are: to insure a thorough burning of the block, to provide a lighter weight block; to enable the block to be easily grasped and placed in the wall during construction; to provide a better bond between mortar and block; and to lessen the tendency for the block to crack.



Common brick base, or pedestal, type of perforated radial brick chimney

Some manufacturers provide corrugations on the sides of the blocks spaced about ⅜ in. apart, the size of the corrugations averaging ⅛ in. in depth and ⅜ in. in width. The avowed purpose of the corrugations is to insure a better bond than is possible with blocks having smooth sides.

Each block has a slightly curved face and back so that when it is laid in the wall, it will conform as closely as is practically possible to the theoretical hollow circle of the chimney section. In order to avoid duplication, each of the various sizes has the same radius which averages about 36 in. Any deviation from the theoretical dimension is taken care of in the vertical joint, so that in chimneys with large diameters the circumference will have the magnified appearance of a succession of short chords and with small diameters, the magnified appearance of a fluted column.

Perforated radial blocks are manufactured in two different colors, viz: red and buff. The red colored block are manufactured from shale material which contains the relatively greater percentage of silicates and the buff colored blocks from clay material which contains the relatively greater percentage of aluminates. The color in the red blocks is due to the presence of iron oxides in the shale. The buff colored blocks are the more highly refractory of the two.

The design and arrangement of radial brick and common brick chimneys follow along the same general lines. A typical structure has the general form, or shape, of a hollow truncated cone tapering from the bottom upwards. With the smaller sizes, the batter of the outside walls is constant from bottom to top while with the larger sizes, the batter percentage decreases by sections towards the top. The theoretical outline of the shaft is a form of a logarithmic curve decreasing in concavity towards the top but due to constructional difficulties the outline is broken up into several sections, the number depending upon the height, the batter of any one section being constant. A succession of different tapers, or batters, is called a multiple taper, or multiple batter, system.

The wall thickness increases by sections towards the bottom, the length of the section also decreasing toward the bottom. The wall thickness remains constant throughout any one section. This is due to the fact that the walls are built up of standard sizes of material and the thicknesses are limited to the combinations which can be made from these sizes. The thickness at any horizontal cross-section must be such that the maximum com-

pression at the leeward side due to weight of material and wind pressure will not exceed the pre-assumed value for the masonry in compression, and also that the tensile stress at the windward side will not exceed the pre-assumed value for the masonry in tension. The standard average area and flexure equations are ordinarily used in determining the various stresses.

The shaft of a brick chimney is reinforced circumferentially by means of steel bands laid endwise and imbedded in the masonry about 4 in. from the outside surface. These bands are usually located directly below each offset in the masonry, above and below the breaching opening, at the top and bottom of the shaft, and in the region at the top of the lining. The purpose of the bands is to resist the circumferential stresses and also to prevent cracks from developing in the walls and opening seriously. No vertical reinforcement is provided in brick chimneys, the small amount of tension usually allowed being resisted by the tenacity of the mortar joints.

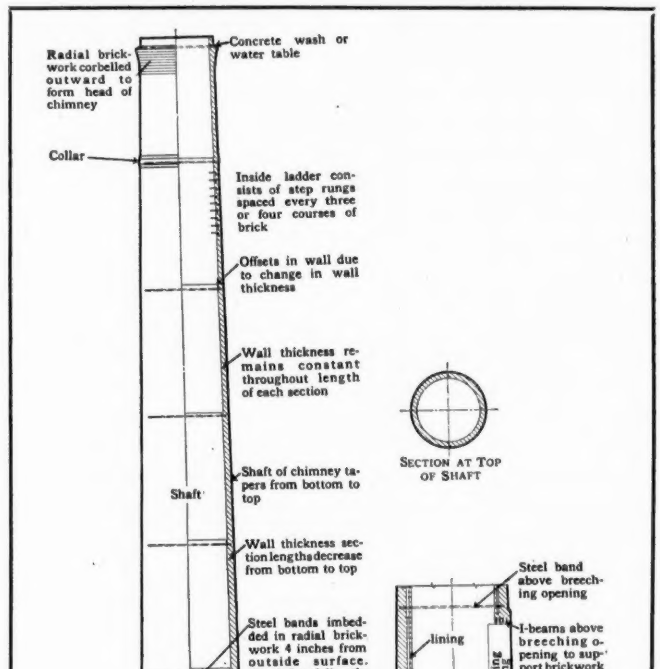
The breeching opening, which obviously is the weakest part of the structure, is reinforced laterally on the sides by means of heavy pilasters built integrally with the walls of the shaft. These pilasters range from 18 to 36 in. in width on the face and extend outward about 3 in. from the line of the shaft. The brickwork above the opening is supported by means of steel lintels which should be protected from the injurious effects of the gases. Steel beams to support the pilasters are imbedded in the masonry below the bottom of the opening. The pilasters are often tied together by means of tie rods extending from side to side.

Brick chimneys are always lined, the height, thickness and arrangement and also the character of the material, depending upon the temperature of the chimney gases. For typical boiler purposes, where the chimney gas temperature does not exceed 600 deg. fahr., the lining usually starts at the bottom of the shaft and extends upwards to a height from 20 to 30 ft. above the top of the breeching opening. At one time it was the usual practice to start the lining a few feet below the bottom of the breeching opening but this arrangement was unsatisfactory. Soot collecting in the bottom of the chimney may ignite and burn briskly with disastrous results unless the lower part is lined. The thickness of the lining is usually 4 in. for an unsupported height of approximately 40 ft. beyond which the thickness increases one inch or so for every 40 ft. increase in height. The material is usually radial blocks, the same material of which the shaft is built. The blocks are laid up in a sand-lime-cement mortar. The main purpose of the lining in a typical chimney of this type is to protect the region around the breeching opening from the injurious effects of the hot gases and also the lower part of the chimney from the effects of fire in case the soot burns.

When radial brick chimneys are used in installations where high temperatures are encountered, such as in waste heat installations, the lining is usually extended up to the constriction level, or the level of the shaft where any further increase in the height of the lining will result in an area inside the lining less than that at the top of the shaft. Radial brick or second grade firebrick is used, the thickness arrangements being as noted in the previous paragraph. When excessively high temperatures (greater than 1500 deg. fahr.) are encountered, the chimney should be lined throughout its entire height with a high grade of firebrick laid up in fireclay with a thin joint.

The chief advantages of radial brick chimneys are: relatively high refractory qualities of mate-

(Continued on page 44)



All-circular type of perforated radial brick chimney

Liquefaction of Gaseous Mixtures*

By WM. L. DEBAUFRE
International Combustion
Engineering Corporation
New York

The content of this article is especially applicable to steam plant problems. Questions involving design of equipment used in the boiler and turbine room and the selection of materials for the fabrication of such equipment require a knowledge of the behavior and characteristics of gaseous mixtures such as the products of combustion and steam-air mixtures. The process of liquefaction of such mixtures results in changes in the composition of the various components which affect the condensation temperature of the mixture. For instance, an impurity in steam, having a higher boiling point than water, will appreciably increase the temperature at which condensation starts; also the dew point temperature of the products of combustion is affected by the amount of sulphur present in the gases . . . Mr. DeBaufre's discussion of the fundamentals of the liquefaction of gases will be interesting and instructive to designing and operating engineers as well as to students of the subject.

WHEN two or more components of a gaseous mixture are liquefied by reduction in temperature below the dew point, the liquefied portion of the mixture contains these components in a different proportion than in the gaseous portion of the mixture in contact with the liquid. As liquefaction proceeds, the compositions of both the liquid and gaseous portions change. The liquid portion contains in solution not only those components of the gaseous mixture which condense when pure at temperatures near the dew point of the mixture, but also the other components which have considerably higher condensing temperatures. These latter components also are dissolved in the liquid in a different proportion than existing in the gas.

These facts form the basis for many industrial processes involving the separation of gaseous and liquid mixtures, such as atmospheric air into oxygen, nitrogen, etc., crude petroleum into gasoline, lubricating oil, fuel oil, etc. In other industrial processes, they have a bearing which is often not fully appreciated. Thus, in power plants, the boiler feed-water contains dissolved gases from atmospheric air, but in a different proportion than existing in the atmosphere. Also, the dew point temperature of the products of combustion depends not only upon the percentage of water vapor present but also upon the relative amounts of SO_2 and SO_3 formed from the combustion of the sulphur in the fuel.

Before discussing these matters, we will first consider the condensation of steam-air mixtures in condensers, feed-water heaters, etc., as a relatively simple example of the liquefaction of gaseous mixtures.

Steam-air Mixtures

The steam entering condensers and feed-water heaters in power plants, and entering evaporators and other steam-heated apparatus in manufacturing plants, contains more or less "non-condensible gases" due to air leakage into the systems where the pressure is below atmospheric and to air dissolved in the water fed to the steam boilers. For steam condensing apparatus operating below atmospheric pressure, air pumps must be provided to withdraw the non-condensible gases in order to maintain the desired vacuum. For steam condensing apparatus operating above atmospheric pressure, means must be provided to discharge the non-condensible gases or the apparatus will become "air bound" and no steam will enter to supply heat by condensing. The failure of steam radiators to heat buildings when the air valves do not function properly is a familiar example of such accumulation of non-condensible gases.

Near the inlet of steam to the apparatus in question, the ratio of non-condensible gases to steam is generally so small that the temperature of the mixture is practically the same as that of saturated steam corresponding to the total pressure of the mixture. As the steam flows through the apparatus and partly condenses, however, the ratio of gas to steam increases until the partial pressure of the non-condensible gases becomes an appreciable fraction of the total pressure and the temperature of the mixture becomes appreciably less than that of saturated steam corresponding to the total pressure. With increase in partial pressure of the non-condensible gases, their volume becomes less. This is of advantage in reducing the displacement of the air pump required to maintain a given vacuum. Or, if the apparatus operates above atmospheric pressure, a higher partial pressure with smaller

volume of the non-condensible gases means that less steam is lost with the non-condensible gases when they are discharged from the apparatus. The non-condensible gases are generally assumed to be dry atmospheric air.

The calculation of the volume of a steam-air mixture for unit weight of dry air therein is based on the fact that at temperature t and under total pressure p, the partial pressure p_a of dry air present is equal to the total pressure p minus the pressure p_s of saturated steam corresponding to the temperature t. Since the density of dry air at 32 fahr. and under 29.921 inches of mercury is 0.08069 lb. per cu. ft., the volume of dry air in cubic feet per pound at temperature t fahr. and under $p—p_s$ inches of mercury is

$$v_a = \frac{1}{0.08069} \times \frac{29.921}{p - p_s} \times \frac{t + 459.6}{32 + 459.6}$$

$$= 0.7543 \frac{t + 459.6}{p - p_s}$$

The curves of Fig. 1 were calculated by means of the above relation and show how the volume of one pound of dry air decreases as the temperature of a steam-air mixture drops and the ratio of dry-air to steam increases.

With condensing steam engines, the amount of air entering the condenser per 1000 lb. of steam varies normally from about 3 lb. with small engines to 1 lb. with large engines. With condensing steam turbines, the air leakage is less, so that the air entering the condenser per 1000 lb. of steam varies normally from 1 lb. with small turbines to 0.2 lb. or less with large turbines. With apparatus operating above atmospheric pressure, the non-condensible gases contained initially in the steam condensed therein is much less than given above for condensing steam engines and turbines. Hence, by reference to Fig. 1, it is seen that normally over 99 per cent of the steam is condensed before an appreciable drop in temperature occurs.

Composition of Dissolved Gases

Water in contact with atmospheric air at 68 fahr. and under normal barometic pressure, will absorb 0.0187 of its volume of dry gases reduced to 32 fahr. and 29.92 inches of mercury. This is equivalent to about 0.0187 × 0.08069 × 0.01605 × 1000 = 0.024 lb. of dry gases per 1000 lb. of water, which may be compared with the preceding figures for the air entering condensers per 1000 lb. of steam. In this computation, 0.01605 cu. ft. per lb. is the specific volume of water at 68 fahr. and 0.08069 lb. per cu. ft. is the density of dry air at 32 fahr. and 29.92 inches of mercury.

The composition of the absorbed gases, however, is not the same as that of the dry gases in the atmosphere due to the different degrees of solubility of the several components. Thus, the dissolved gases comprise about 34 per cent of oxygen instead of 21 per cent as in the atmosphere. Also, the dissolved carbon dioxide is over one per cent as compared with about 0.03 per cent in the atmosphere. The different degrees of solubility of oxygen, nitrogen and carbon dioxide are indicated by the fact that one cubic foot of water will absorb 0.0315 cu. ft. of oxygen or 0.0157 cu. ft. of nitrogen or 0.8754 cu. ft. of carbon dioxide when in equilibrium with each gas under 29.92 in. of mercury and at 68 fahr.

The above figures indicate the possibility of errors in gas analyses if care is not taken to bring the water in the measuring burette into equilibrium with gas of the composition to be analyzed before a sample is taken into the burette for measurement. Errors may also result from collecting the gas sample over water not previously in contact with gas of about the same composition. For this reason, mercury is sometimes used in the sampling apparatus and also in the measuring burette of the analysis apparatus.

The degree of solubility depends upon the liquid as well as upon the gas. Thus, the hydrochloric acid solution of cuprous chloride used in gas analysis apparatus for absorbing carbon monoxide does not act upon the gas chemically but the carbon monoxide goes into solution until equilibrium is reached between the tendency for the dissolved carbon monoxide to escape from the solution and the partial pressure of carbon monoxide in the gaseous mixture. This liquid was chosen by reason of the very high solubility of carbon monoxide in it. Unless replaced by fresh reagent, however,

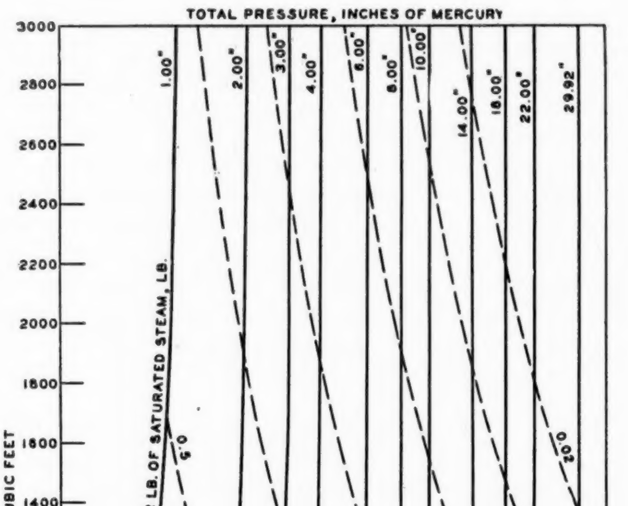


Fig. 1—Volume of one pound of air in a mixture of saturated steam and air.

the amount of carbon monoxide in solution eventually becomes so large that no more is absorbed from the gas.

At pressures other than atmospheric, the amount of gas dissolved in a liquid is approximately pro-

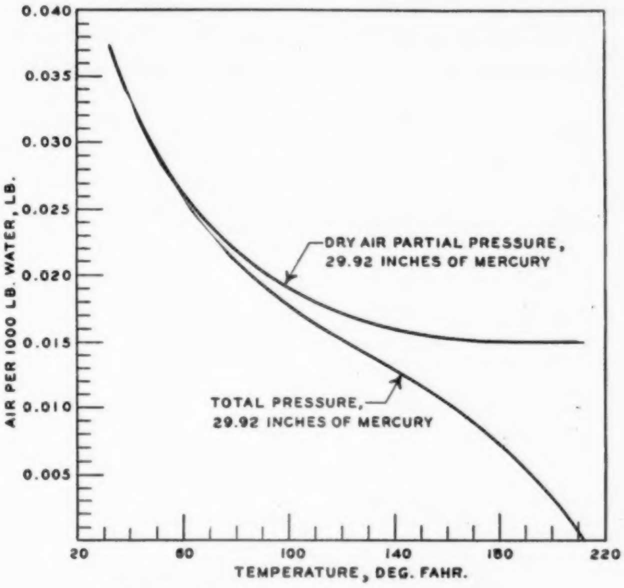


Fig. 2—Solubility of dry air in water.

portional to the pressure of the gas in contact with the liquid as first discovered by Henry in 1803. Thus, the partial pressure of carbon dioxide in atmospheric air is 0.0003 atmosphere; hence, the amount of carbon dioxide dissolved in one cubic foot of surface water at 68 fahr. in equilibrium with atmospheric air is $0.8754 \times 0.0003 = 0.00026$ cu. ft. reduced to normal conditions. By compressing the air to say 10 atmospheres pressure and then bringing it into contact with surface water, carbon dioxide would be absorbed until equilibrium is again reached. By this means, the percentage of carbon dioxide in the air can be reduced. Surface water is often used for scrubbing industrial gases to remove carbon dioxide therefrom.

The solubilities of various gases in different liquids can be found by experiment only and vary greatly with the temperature. Thus, the upper curve in Fig. 2, based on data in the International Critical Tables, shows the variation with temperature of the weight of dry air dissolved in water when the partial pressure of the dry gases is 29.92 inches of mercury. When water is heated, however, the total pressure including that of the water vapor is generally maintained constant instead of the partial pressure of the dry gases. The latter therefore decreases as the temperature rises, becoming zero at 212 fahr. under normal atmospheric pressure. Since the amount of dry gases in solution varies directly with their partial pressure, the weight of dry air in solution in 1000 lb. of water must become zero at 212 fahr. under normal atmospheric pressure as indicated by the lower curve in Fig. 2. This explains how an open feed water heater reduces the oxygen in boiler feed water to a very small quantity.

Liquefaction of Two or More Components

When two or more components of a gaseous mixture liquefy, the proportions of the components in the liquid and in the gas in equilibrium with the liquid can be found by experiment only. When only two components are involved, the experimental results may be very conveniently shown on a phase equilibrium diagram such as Fig. 3 for ethyl alcohol and water. The boiling point of mixtures of these two fluids varies under normal atmospheric pressure as shown by the lower line in Fig. 3 from 212 fahr. for pure water to 173 fahr. for pure alcohol. There is a minimum boiling point of 172.8 fahr. around 0.8 mole fraction of alcohol, about 91 per cent alcohol by weight. The dew point temperature at which the first drop of liquid forms in cooling gaseous mixtures of alcohol and water is shown by the upper line.

A liquid mixture containing 0.1 mole fraction of alcohol, about 22 per cent alcohol by weight, has a boiling point of about 185 fahr. as shown by point A on Fig. 3. The first particle of vapor formed contains about 0.53 mole fraction of alcohol, about 74 per cent alcohol by weight, as shown by point B. As heat is applied to vaporize the mixture, the temperature rises and the compositions of both liquid and vapor change. At 195 fahr., for example, the liquid composition has changed to about 0.04 mole fraction of alcohol, point C, while the vapor composition has changed to 0.37 mole fraction of alcohol, point D. As indicated by point E, the liquid will be completely vaporized at 207 fahr. and the composition of the last drop of liquid will contain 0.01 mole fraction of alcohol, point F.

The above variation in liquid and vapor compositions of mixtures of ethyl alcohol and water is based on the assumption that all vapor formed is maintained in contact with the liquid remaining so that the liquid and vapor phases can be in equili-

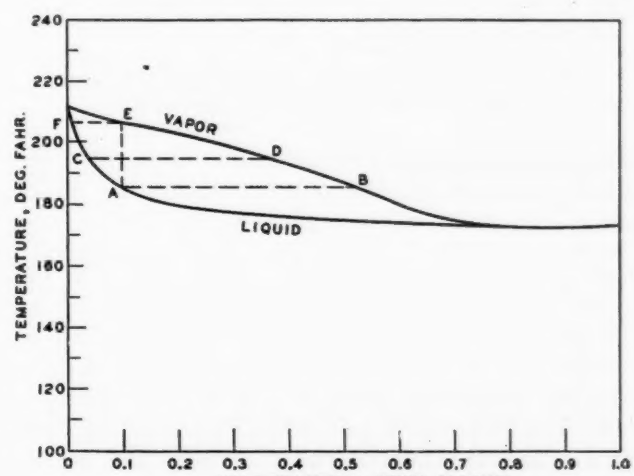


Fig. 3—Phase equilibrium diagram for mixtures of ethyl alcohol and water.

brium. If the vapor be removed as fast as formed, the liquid remaining will lose its alcoholic content more rapidly, becoming practically pure water before the last drop is evaporated. This fact explains

the loss of alcohol from the radiators of automobiles, the alcohol being used to lower the freezing point of the water below 32 fahr.

Dew Point of Products of Combustion

In the preceding article on the "Humidity of Gaseous Mixtures," the dew point was taken as the temperature of saturated steam corresponding to the partial pressure of the water vapor in the mixture. The dry gases present were considered to

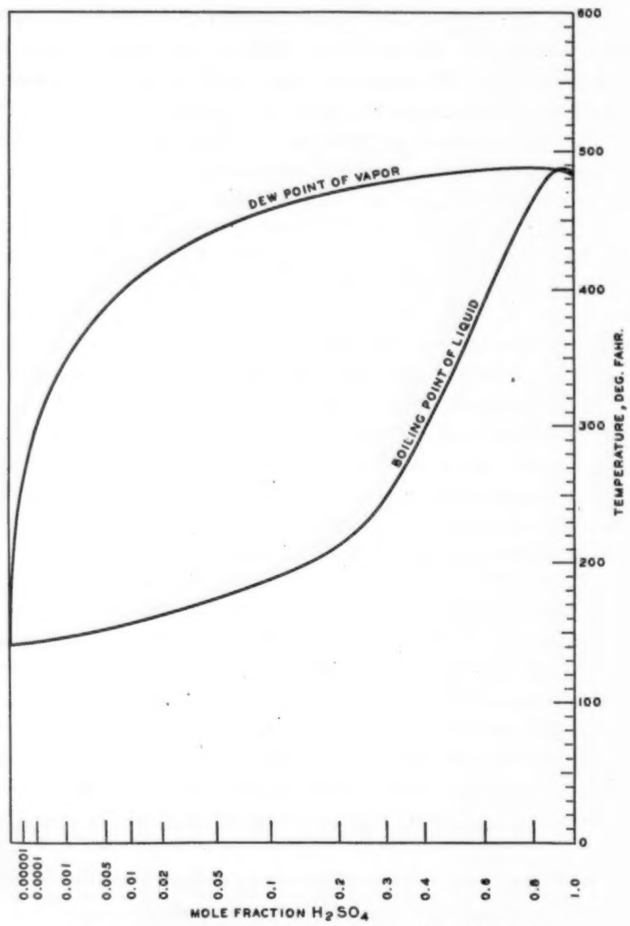


Fig. 4—Phase equilibrium diagram for H_2SO_4-H_2O mixtures. Total pressure 0.2 atmosphere.

have no effect upon the dew point. This, however, is not strictly true. The other constituents, by going into solution with the moisture present, change the dew point from that of pure water. In general, they are more volatile than water and the dew point is slightly lowered. With atmospheric air, the change is negligible; but for products of combustion, the dew point is considerably raised by the presence of minute quantities of SO_3 as shown by R. F. Nielsen in an unpublished report of the Technical Research Department of International Combustion Engineering Corporation.

In the combustion of fuels, the sulphur present is generally assumed to be completely burned to sulphur dioxide (SO_2). In passing through the boiler setting, however, a portion of the sulphur dioxide is oxidized to sulphur trioxide (SO_3) through the catalyzing action of the refractories. Nearly all of this sulphur trioxide immediately combines with water vapor to form sulphuric acid (H_2SO_4) vapor. An equilibrium diagram for mixtures of sulphuric acid and water under a total vapor pressure of 0.2 atmosphere is shown in Fig. 4. A cube root scale was selected for the mole fraction of H_2SO_4 in the mixture in order to show the effects of very small amounts of sulphuric acid in the vapor phase.

By referring to Fig. 4, it is seen that the dew point of pure water vapor having a partial pressure of 0.2

TABLE I.—EFFECT OF SULPHUR ON DEW POINT TEMPERATURE

SO_3 (H_2SO_4) partial pressure, atm.	Dew point temperatures, deg. fahr., for H_2O partial pressures of 0.05 atm.	0.10 atm.	0.15 atm.	0.20 atm.
0	92	115	130	141
0.00001	257	269	276	281
0.00002	272	284	291	296
0.00005	292	304	312	317
0.0001	306	319	327	332
0.0002	321	335	342	348
0.0005	341	355	363	369
0.001	356	370	378	384
0.002	371	385	394	400
0.005	391	406	415	421

atmosphere is 141 fahr. If, however, the partial pressure of the SO_3 (H_2SO_4) present is 0.0001 atmosphere, the dew point will be raised to 332 fahr. corresponding to a mole fraction of H_2SO_4 in the vapor equal to 0.0001 / (0.2 + 0.0001) = 0.0005. The first particle of liquid condensed at 332 fahr. will contain 0.48 mole fraction, about 84 per cent by weight, of sulphuric acid.

The amount of liquid formed, however, is very small until the temperature is reduced considerably below the dew point. This fact together with the probability that very little of the sulphur dioxide is usually oxidized to sulphur trioxide, explains the freedom from corrosion of economizers and air preheaters wherein the products of combustion are cooled to lower temperatures than the dew points given in Table I for various partial pressures of water vapor and sulphuric acid. Some tests to determine the effect of furnace refractories in catalyzing the oxidation of SO_2 to SO_3, indicated about one-third of the SO_2 was changed to SO_3 with a certain coal containing 3.4 per cent sulphur. Since relatively more samples were undoubtedly taken near the refractory walls than near the middle of the furnace, this fraction is probably too large. The average amount oxidized is probably one-fifth or less.

Impurities in Steam

In preceding parts of this article have been discussed the effects of "non-condensible gases" on the condensation of steam. Such gases are in reality condensible if the temperature is reduced to a very low value and they should therefore be classified as high volatile impurities. Their presence always reduces the temperature at which steam condenses under a given total pressure.

Later was discussed the vaporization and condensation of mixtures of alcohol and water. A small quantity of alcohol might be considered as an impurity in steam and its effect upon condensation is shown by the left-hand end of the phase equilib-

ium diagram in Fig. 3. Alcohol is somewhat more volatile than water and the presence of a small amount slightly lowers the temperature at which condensation occurs under a given pressure. This effect, however, cannot be taken as applying to all impurities slightly more volatile than water. When the impurity has about the same boiling point as water, the effect upon the temperature of condensation can be determined only by reference to a phase equilibrium diagram for the impurity in question. In any case, a small amount of such an impurity will have a slight effect only on the condensation temperature.

When an impurity in steam has a much higher boiling point than water, its effect is to considerably raise the temperature at which condensation starts as the steam is cooled under a given pressure. This has been illustrated by the effect upon the dew point of the presence of small quantities of sulphuric acid vapor in moist products of combustion. It is also true of other volatile impurities, many of which are ordinarily spoken of as "non-volatile." Thus, we should expect minute quantities of low volatile impurities, present in steam by reason of their existence in boiler feed water, to raise the condensation temperature of the steam and therefore be deposited on turbine blades in a region where calculations based on pure steam would indicate the steam to be still in the superheated condition rather than have reached the saturation temperature.

Liquefaction of Atmospheric Air

The separation of oxygen from atmospheric air for cutting and welding purposes is generally accomplished by a so-called liquefaction process in which the air is more or less completely liquefied before being subjected to rectification. The latter process for separating gaseous or liquid mixtures depends upon the fact that the proportions of the various constituents are different in the liquid and gas phases in equilibrium at a given temperature and under a certain total pressure. The phase equilibrium diagram for oxygen and nitrogen is therefore of great industrial importance in showing how the main components of atmospheric air selectively liquefy or vaporize under a constant pressure as the temperature is lowered or raised.

The phase equilibrium diagrams for oxygen and nitrogen in Fig. 5 are based on experimental data. It will be noticed that these diagrams are comparatively simple in shape. This is due to the similar characteristics of oxygen and nitrogen. In such cases, the phase equilibrium diagram may be determined with a fair degree of accuracy by means of certain mathematical relations which have been developed for perfect solutions.

Relations for Perfect Solutions

Perfect solutions may be defined as those in which the components mix in all proportions without any thermal changes. The physical and chemical characteristics of the components must be similar so that the thermodynamic environment does not change as the composition is varied. Certain mathematical relations first developed for dilute solutions where the thermodynamic environment changes very little with variation in

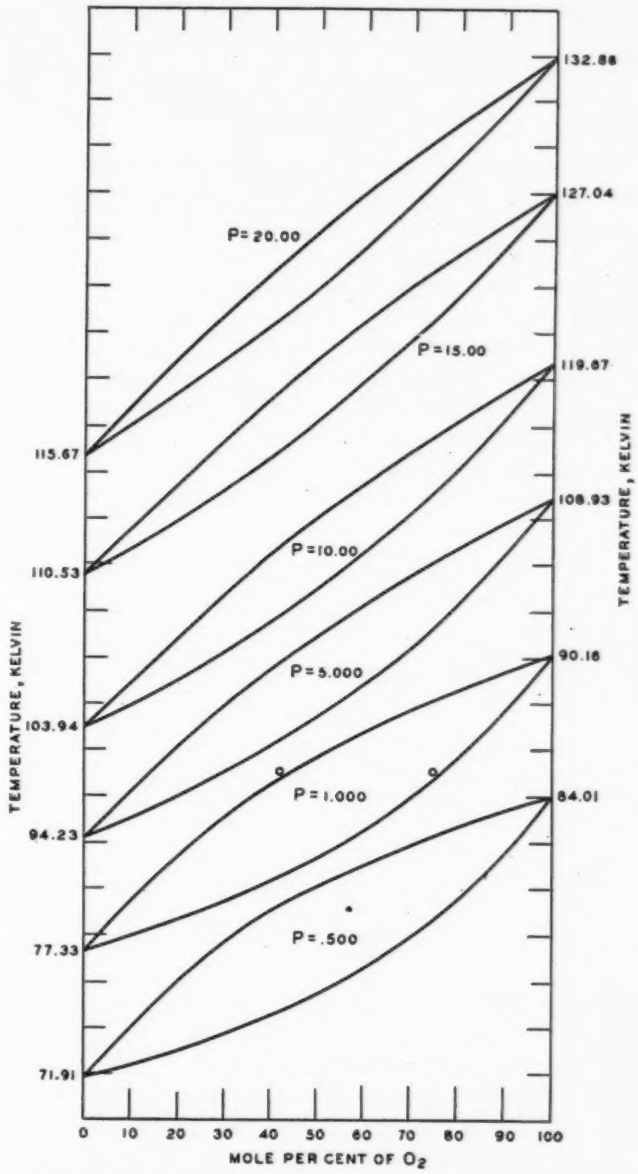


Fig. 5—Phase equilibrium diagram for oxygen-nitrogen. Pressure P is in atmospheres. Temperature rule, one division=2 deg. cent.

composition have been applied to more concentrated solutions of substances having similar characteristics. These relations may be utilized to calculate the properties of perfect solutions.

Thus, Henry discovered in 1803 that the solubility of a gas in a liquid is proportional to the partial pressure of the gas; that is,

$$p_1 = K \frac{n_1}{n_1 + n_2}$$

where p_1 is the partial pressure of the absorbed gas having a mole fraction n_1 in a solution wherein the other (liquid) component has a mole fraction n_2. Raoult showed (1878 to 1888) that the lowering in vapor pressure of a solvent by the addition of a non-volatile substance was proportional to the concentration of the latter; that is,

$$\frac{p_0 - p_1}{p_0} = \frac{n_2}{n_1 + n_2}$$

where p_0 is the vapor pressure of the pure solvent and p_1 is the vapor pressure after adding some non-volatile substance until its concentration becomes n_2 moles to n_1 moles of the solvent. Solving for p_1, we obtain

$$p_1 = p_0 \frac{n_1}{n_1 + n_2}$$

Thus, Raoult's law is the same mathematically as Henry's law except that K is replaced by p_0. Henry's law was derived for a dilute solution in which n_1 is small while Raoult's law was derived for a dilute solution having a small value of n_2.

For a perfect solution, we may apply this expression to all proportions of n_1 and n_2 and utilize it to calculate the mole fractions of these two components in a liquid at a given temperature t and under a given total pressure p.

If p_0' and p_0'' are the saturation pressures at temperature t for components n_1 and n_2 respectively, we have

$$p_1 = p_0' \frac{n_1}{n_1 + n_2} \text{ and } p_2 = p_0'' \frac{n_2}{n_1 + n_2}$$

The sum of the partial pressures p_1 and p_2 of the two components must equal the total pressure p, and $n_1 + n_2 = 1$. Hence,

$$n_1 = \frac{p - p_0''}{p_0' - p_0''} \text{ and } n_2 = \frac{p - p_0'}{p_0'' - p_0'}$$

The mole fractions of the two components in the vapor are equal simply to the respective partial pressures divided by the total pressure; that is

$$N_1 = \frac{p_1}{p} = \frac{n_1 p_0'}{p} \text{ and } N_2 = \frac{p_2}{p} = \frac{n_2 p_0''}{p}$$

where N_1 and N_2 are the mole fractions of the two components in the vapor and $N_1 + N_2 = 1$.

Under one atmosphere absolute pressure, the boiling point of pure nitrogen is 77.4 Kelvin while that of pure oxygen is 90.15 Kelvin. Hence the phase equilibrium diagram of oxygen-nitrogen will extend between these two temperatures for a total pressure of one atmosphere absolute. At 85 K., the corresponding compositions of liquid and vapor may be calculated by means of the above relations as follows: The saturation pressure of nitrogen at 85 K. is 2.276 atm. and of oxygen is 0.564 atm. Hence,

$$n_1 = \frac{1 - 2.276}{0.564 - 2.276} = 0.745 \text{ mole fraction of oxygen in liquid.}$$

$$n_2 = \frac{1 - 0.564}{2.276 - 0.564} = 0.255 \text{ mole fraction of nitrogen in liquid.}$$

$$N_1 = \frac{0.745 \times 0.564}{1} = 0.420 \text{ mole fraction of oxygen in vapor.}$$

$$N_2 = \frac{0.255 \times 2.276}{1} = 0.580 \text{ mole fraction of nitrogen in vapor.}$$

These calculated points are marked on Fig. 5 to show how close they correspond to the curves based on experimental data.

Thermal Changes During Liquefaction

For perfect solutions, in which the components mix in all proportions without any thermal changes, the thermal changes during liquefaction and vaporization may be readily calculated from the thermal properties of the pure components. Thus, the total heat of the liquid mixture at the boiling point temperature t_1 may be taken as equal to

$$h_f = xh_f' + x_2h_f''$$

where x_1 = mole fraction of first liquid component,
x_2 = mole fraction of second liquid component,
h_f' = total heat per mole of first liquid component at temperature t_1,
h_f'' = total heat per mole of second liquid component at temperature t_1 and
h_f = total heat per mole of liquid mixture at the boiling point.

The total heat of the vapor mixture at the dew point temperature t_2 under pressure p is equal to

$$h_g = x_1h_g' + x_2h_g''$$

where x_1 = mole fraction of first vapor component,
x_2 = mole fraction of second vapor component,
h_g' = total heat per mole of first vapor component at temperature t_2 and under its partial pressure $p_1 = x_1p$,
h_g'' = total heat per mole of second vapor component at temperature t_2 and under its partial pressure $p_2 = x_2p$, and
h_g = total heat per mole of vapor mixture at the dew point under total pressure p.

The heat abstracted in liquefying the mixture under a constant pressure p is then given by

$$h_{fg} = h_g - h_f$$

Similar relations apply to changes in internal energy and in entropy.

However, if we do not have a perfect solution, the thermal changes due to the components going into solution with each other must be taken into account. The total heat is then some function of the proportions x_1 and x_2 of the two components. Expressed mathematically, the total heat of the liquid mixture

$$h_f = f(x_1, x_2)$$

Or,
$$h_f = \frac{\delta h_f}{\delta x_1} \times x_1 + \frac{\delta h_f}{\delta x_2} \times x_2$$

Where $\frac{\delta h_f}{\delta x_1}$ = rate of change of total heat with the mole fraction x_1 of the first component and

$\frac{\delta h_f}{\delta x_2}$ = rate of change of total heat with the mole fraction x_2 of the second component.

In order to calculate the total heat of the liquid mixture, it is necessary to have available values of the rates of change of the total heats of the two components corresponding to their mole fractions,

(Continued on page 29)

The Chemical Nature of Coal

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PART TWO

New Light Upon the Origin and Character of the Coking Constituents of Coals . . .

Professor Bone's first article on the chemical nature of coal was published in the February, 1931, issue of COMBUSTION. The present article, the second in the series, deals with experiments which, as the author expresses it, throw new light upon the coking properties of various coals. Professor Bone, in the concluding paragraph of his article, stresses the importance of the extended use of the methods of organic chemistry if real progress is to be made in the realization of the full commercial value of this basic raw material.

MY previous article chiefly dealt with the newly discovered benzenoid character of the main coal substance arising out of experiments upon the alkaline permanganate oxidation of the residues remaining after coals have been extracted with benzene under pressure. In this article, I propose showing how investigations upon the benzene-pressure-extract have thrown light upon the maturing of coals and the origin and character of their coking constituents.

In order that readers may better understand precisely what is meant by the "benzene-pressure-extraction" of coals, a brief description of the process is given to serve as an introduction to a discussion of the important results which have recently followed therefrom.

Generally speaking, with the exception principally of certain brown coals containing "Montana wax," coals, regardless of their age and maturity, yield but little to the solvent action of boiling benzene at atmospheric pressure. On raising the pressure, however, more is yielded; and, when boiling benzene is used at pressures of between 250 and 700 lb. per sq. in. (corresponding with temperatures of between 240 and 285 deg. cent.) more or less considerable "extracts" are obtained, there being a quite definite "end-point" to the extraction at the highest pressure named.

In practice, the extraction is best carried out on the "soxhlet" principle in a specially designed pressure vessel. In such-wise, anything up to about 15 per cent of the dry ashless coal substance passes into solution in the benzene, leaving 85 per cent or more of a residue. Moreover, it is important to note that with all coking bituminous coals, the benzene-pressure-extraction always contains the coking constituents, the residue being quite devoid of coking propensities. So far, indeed, no exception has been found to this rule.

It may be stated here in passing that such benzene-pressure-extraction has so many advantages over the older and more generally used pyridine-extraction of coals that, for scientific purposes at least, it is much to be preferred. Indeed, in my experience, pyridine extraction followed as is usual by a chloroform extraction of the pyridine-extract, is of little value, and its supposed resolution of the coal substance into so-called α, β and γ constituents is mostly meaningless for scientific purposes.

The crude benzene-pressure-extract obtained by the process just described may be resolved by suitable after-treatment into *four* different fractions, of which *three* are each chemically quite distinctive. In the cases of bituminous coals these fractions may be described as:

1. *A yellow-brown viscous non-nitrogenous neutral oil* (usually of a "vaseline" consistency) of high hydrogen to carbon ratio and low oxygen content, soluble in light petroleum and apparently of aliphatic constitution.

2. *A reddish-brown solid of very low softening power,* usually below 60 deg. cent. soluble in a

mixture of four parts of light petroleum and one part of benzene.

3. *A non-nitrogenous (or nearly so) reddish-brown and brittle resinous solid,* of fairly low softening point, usually below 150 deg. cent., insoluble in light petroleum but soluble in ethyl alcohol.

4. *A neutral, amorphous, cinnamon-brown, nitrogenous powder,* insoluble in both light petroleum, ether and ethyl alcohol, and softening at temperatures usually well above 150 deg. cent. (generally somewhere between 150 and 250 deg. cent.) Undoubtedly this fraction has a "benzenoid" structure.

It should be noted that Fractions 1 and 2 are comprised in what F. Fischer calls the "Oelbitumen" and Fractions 3 and 4 in what he calls the "Festbitumen" of coals, though we like not such names. The most important things to observe, however, are, first, that while Fraction 1 never, and Fraction 2 but seldom, has any binding properties, both Fractions 3 and 4 always have; and second, that it is the latter fractions, especially Fraction 4, which are chiefly responsible for the coking propensities of bituminous coals. Indeed, so far as our present knowledge goes, it can be said that, while non-caking or only slightly caking bituminous coals are always deficient in Fraction 4, strongly coking coals yield between 5 and 10 per cent of it, and that the coking propensities of a coal are directly related to the yields of this fraction. Fraction 3, although having strong binding properties, is generally present in too small quantities to influence matters otherwise than by reinforcing the effects of Fraction 4.

So much then for bituminous coals, which alone display coking propensities. The still maturer semi-bituminous and anthracitic coals, all of which are devoid of such propensities, yield little or no benzene-pressure-extract, a circumstance which explains their non-coking properties. It would seem as though, presumably through the seam having been affected by heat due either to neighboring igneous intrusions or to friction caused by earth movements, semi-bituminous and anthracitic coals have lost their former contents of bodies yielding these fractions, and with them any coking propensities which formerly they may have possessed.

With regard to the less mature sub-bituminous coals, lignites and brown coals, none of which are "cokers," it has been found that while they always yield Fractions 1 and 2, in proportions usually comparable with (and sometimes even greater than) those yielded by bituminous coals, they are either very deficient in Fractions 3 and 4, or do not yield them at all. And in this connection a most significant and important new observation comes in, which supplies a valuable clue to the whole problem of the maturing of coals and development of coking propensities in them.

On investigating earthy brown coals of incipient maturing only, it was found that instead of the said Fractions 3 and 4 which indeed are entirely absent, they yield phenolic esters and phenols. When, however, lignitic coals of progressively greater maturity were examined, it was found that on arriving at the laminated black lignitic stage, these phenolic esters and phenols disappeared from the benzene-pressure extract and in their place substances simulating those comprising Fractions 3 and 4 of bituminous coals began to appear. Hence it seemed probable that the Fractions 3 and 4 invariably yielded by laminated black lignites, sub-bituminous and bituminous coals, and which are responsible for the coking propensities of the last named, have originated in the phenols and phenolic esters found in less mature brown coals.

Such conclusion has been strengthened by the results obtained by oxidizing Fraction 4 of some strongly coking coals with a hot solution of chromic acid and alkaline permanganate, applied successively, when 100 parts of such Fraction 4 yielded 62 parts of benzene carboxylic acids, 24 parts of oxalic and 2.4 parts of acetic acid. Thus it was found to have an essentially benzenoid constitution, in accordance with the supposition of its phenolic origin. Hence it may be inferred that what may be termed the "coking constituents" of bituminous coals have a similar benzenoid structure to that of the main coal substance.

Having thus outlined the matter, we may now profitably consider some typical data relating to the yields and character of the various components of benzene-pressure-extracts obtained from some different classes of coals of widely different origins. In the case of the first two brown coals listed in the table, page 29, an asterisk opposite the yields of Fractions 3 and 4 indicates that there were phenolic esters and phenols, respectively, which, according to the foregoing view, preceded and caused the formation of these fractions in the more mature coals.

It will be seen that while the coking propensities of the coals can in no way be correlated with their yields of Fraction 1, even with those of 3 and 2 combined, they are closely related either to the yields of Fractions 2 and 4, or to those of 3 and 4 combined. It should, however, be mentioned that in some of the strongest coking coals examined (e.g. the Busty Durham Coal shown above) Fraction 2 exhibited binding properties, and therefore contributed to the coking propensities. Hence it would appear that sometimes Fraction 2 may influence coking, though never to the same extent as Fractions 3 and 4. On the other hand we have never yet come across a case in which Fraction 1 exhibited any binding properties.

With regard to the maturing of coals during geological time, it should be emphasized that Fractions 1 and 2 are yielded by all coals in common from the youngest onwards. Fraction 1 is always a viscous oil, and in bituminous coals resembles what have been termed the 'primary oils' of their low temperature carbonization which in many cases have good lubricating qualities. As already said, Fractions 3 and 4 do not appear until about the stage of maturity represented by the black laminated lignites; but from such stage onwards ap-

parently they go on gradually developing, replacing the phenols and phenolic esters found in the brown coals, and eventually giving rise to the coking propensities of bituminous coals. Another point which should be remembered is that without

YIELDS OF BENZENE-PRESSURE-EXTRACT FRACTIONS

Coal	Origin	Geological Era	Total Yield of Benzene Extract %	Yield of Fraction 1	2	3	4
Earthy Brown Coal	Morwell, Australia	Tertiary	15.0	3.5	1.5	1.0*	9.0*
Brown Non-Laminated Lignite	Estevan, Canada	Tertiary	4.5	1.65	0.3	0.3*	2.25*
Black Laminated Lignite	Alberta, Canada	Cretaceous	4.3	1.3	1.3	1.2	0.5
Sub-Bituminous	Kaitangala, N. Zealand	Cretaceous	8.2	2.9	1.7	2.4	1.2
Bituminous Non-coking	Witbank, S. Africa	Permo-carboniferous	7.5	1.72	1.97	0.6	3.2
Bituminous Weakly Coking	Shafton, Yorks, England	Carboniferous	10.6	3.5	2.15	2.3	2.68
Bituminous Barnsley Seam Fairly strongly coking	Yorks, England	Carboniferous	8.3	2.2	0.6	0.4	5.1
Bituminous Busty Seam very strongly coking	Durham, England	Carboniferous	15.6	3.3	3.0	0.05	9.25
Semi-bituminous	S. Wales	Carboniferous	1.25	too small an amount for fractionation			
do	N. Spain	Carboniferous	0.5				

* Not true Fractions 3 and 4 but the phenolic esters and phenols from which 3 and 4 of maturer coals have been developed.

exception, the oxygen content of *all* fractions like that of the main coal substance, progressively diminishes as the maturity, of the coal increases.

In this and my previous article I have attempted to show how recent research has thrown new light upon both the chemical nature of coals and their maturity. In doing so, I have necessarily dealt with the matter in broad outline only, confining myself to the main points and omitting many interesting details which, had space permitted, might have been mentioned. I hope, however, to deal fully with the subject in a book upon coal which I am contemplating for American readers in conjunction with my friend Professor Eric Sinkinson of Lehigh University.

Although, in the course of the researches in question, coals of all types and classes, and from many different parts of the world, have been examined, it cannot be claimed that the investigation has been exhaustive. Thus, for instance, although selected lignitic coals from the Western Canadian (Saskatchewan and Alberta) coalfields have been included, as yet no American bituminous coals have been examined. Hence, while there is no *a priori* reason for supposing that they would give results differing radically from those obtained with similar British coals, differences in detail may be expected, and it would be conducive to the advancement of science if our experimental methods and technique could be applied systematically by competent workers to American bituminous coals.

Apart from the particular results dealt with in these articles, however, it may be urged that the coal substance being a complex organic compound ought to be investigated as such by the methods of organic chemistry. In the past fundamental coal research suffered much through neglect of this elementary consideration, and no real headway will be made until it is not only recognized but given effect to. Nowadays Governments and industrialists everywhere are organizing and financing what they are pleased to call "coal research" and quite an army of investigators is engaged upon it; indeed, from being one of the Cinderellas it has become almost the spoilt child of State Departments, so lavishly are its requirements now provided for. But little will come of it all until much more is known than now of the inner chemical constitution of coal; and to elucidate this, more organic chemists must be imported into fuel research laboratories and more reliance placed upon the systematic methods of organic chemistry.

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Liquefaction of Gaseous Mixtures

(Continued from page 26)

and to the temperature of the mixture, such as given in the International Critical Tables for mixtures of water with sulphuric acid, ammonia, etc.

Solutions of various substances in water are so often encountered that the heats of dilution in water have been determined for many substances. The greater the amount of water, the larger is the heat of dilution per unit weight of substance dissolved; but after the dilution has reached a certain point, very little additional heat corresponds to any further dilution. The maximum amount of heat for infinite dilution is sometimes called the heat of complete dilution. For any finite quantity of water, there is a corresponding heat of partial dilution.

References

Most of the data in this article on the solubilities of various gases, etc., have been taken from the International Critical Tables to which the reader is referred for more complete data. A more thorough discussion on the nature and thermal properties of solutions will be found in Lewis and Randall's Thermodynamics and in books on Physical Chemistry by Washburn, by Eucken and by others. The data on oxygen and nitrogen were taken from the article by Dodge and Dunbar entitled "An Investigation of the Coexisting Liquid and Vapor Phases of Solutions of Oxygen and Nitrogen" in the Journal of the American Chemical Society, Vol. 49 pp. 591-610, 1927. Credit is also extended to R. F. Nielsen, formerly on the staff of the Technical Research Department of International Combustion Engineering Corporation, for his calculations and conclusions on the effect of sulphur upon the dew point of moist products of combustion.

John Bell

John Everett Bell, consulting engineer, was born in Ripley, Ohio, May 8, 1876. He attended Ohio State University as a special student . . . . In 1897, Mr. Bell went to Cripple Creek, Colo., where he remained until 1899, being successively chief engineer, superintendent and manager of La Bella Mill, Water and Power Co. He next engaged in consulting work until 1901, when he became identified with the Stirling Boiler Co., where he conducted tests and designed superheaters, marine boilers and mechanical stokers. . . . In 1905, Mr. Bell became assistant to E. R. Stettinius, head of the Stirling Boiler Co., and in 1907 went over, with that organization, to the Babcock & Wilcox Co., where he was engaged in engineering research, particularly in connection with heat-transfer rates. . . He became interested in the development of waste-heat boilers and planned virtually all the installations of the Babcock & Wilcox Co. until he left that organization in 1915. . . . . Mr. Bell then started in business for himself as a consulting engineer. He continued his investigation of waste gases and, in conjunction with the Edge Moor Iron Co. by whom he was retained as consulting engineer, designed and installed forty-six waste-heat installations . . . Mr. Bell also designed the Foster marine boiler, the Foster economizer and the Foster high-pressure boiler and superheater, for the Power Specialty Co. (now, The Foster Wheeler Coorporation). . . . In 1920, Mr. Bell became consultant for Combustion Engineering Corporation. This organization was just entering the field of pulverized fuel utilization and he was called upon to investigate the practicable possibilities of burning pulverized fuel under steam boilers. The rapid progress in this art reflected his intimate knowledge of steam generating practices and his vision. . . . His death, November 27, 1924, deprived the world of a clear-thinking engineer, who had a marked influence on the development of those branches of engineering with which he was identified.

PROGRESS in any branch of engineering represents the combined effect of certain essential factors, the most potent of which are vision, ingenuity, knowledge of fundamentals, and, that rare but necessary element—commercial judgment.

It is seldom that these qualities are combined in a single individual. Usually, fundamental principles are first defined by the scholarly, pedantic type of mind which is interested primarily in pure research. The inceptions of many of our most important engineering developments were, initially, mere principles which lay dormant, veiled

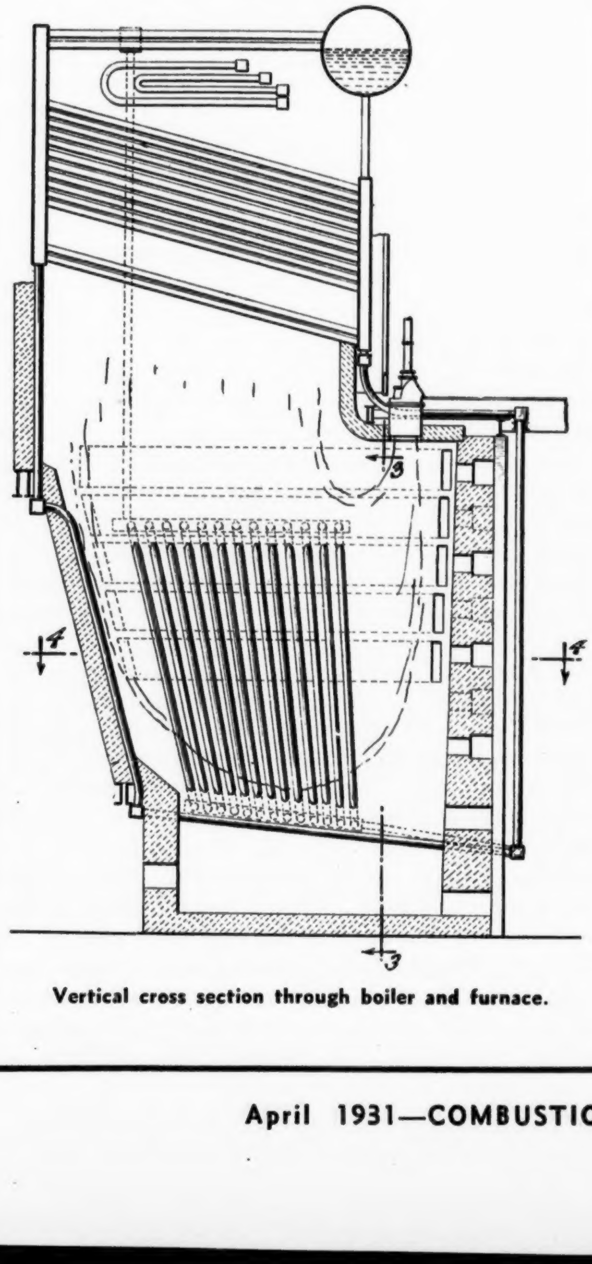
Patented Apr. 9, 1929. 1,708,862

UNITED STATES PATENT OFFICE.

JOHN E. BELL, OF BROOKLYN, NEW YORK, ASSIGNOR TO COMBUSTION ENGINEERING CORPORATION, A CORPORATION OF NEW YORK.

APPARATUS FOR BURNING FUEL.

Application filed September 16, 1922. Serial No. [illegible].



Vertical cross section through boiler and furnace.

Pioneer and Man of Vision

in a mass of abstract formulas until the commercial element was added to translate the potential possibilities of the new idea into logical designs which made possible its practical application.

He who discovers a new principle will probably be spoken of as one "who lived before his time."

He who makes practical application of that principle will be recognized for having accelerated the tempo of his time in the advancement of his art and the resultant saving of precious years in effecting progress.

For true progress does not come from the mere establishing of new principles but rather from their practical application.

The happy faculty of combining fundamental engineering analysis with commercial application is limited to few individuals. This peculiar type of genius was recognized in the late John E. Bell.

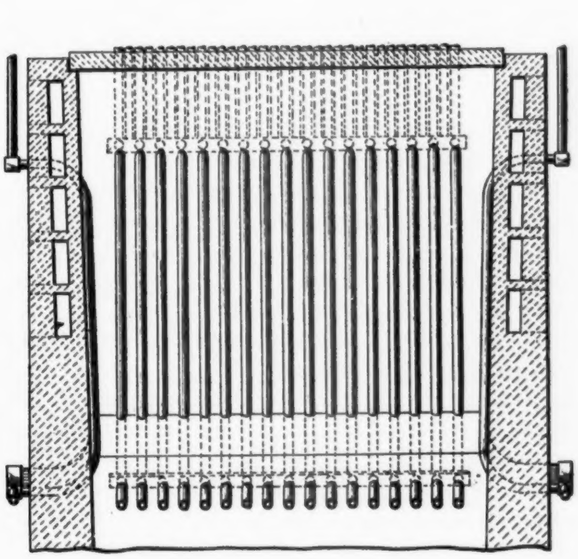
It is ofttimes difficult, in retrospect, to determine whether the ideas of the pioneer were visions of possible future development or whether his initial work was actually a guiding factor in influencing the trends of that development. Perhaps it can be more truly said that the efforts of our most outstanding pioneers represented a combination of vision and influence, in that their intimate knowledge of existing conditions enabled them to see the possibilities of the future and that their constructive ideas served to point the way for developments in their fields of endeavor.

Such a pioneer was John E. Bell—an unusually clear-thinking engineer, thoroughly grounded in the fundamentals of mathematics, chemistry and physics, all woven intimately into a background of practicality and sound commercial judgment. His was a constructive type of mind and the scores of patents granted to him individually, and jointly with his associates, are eloquent testimony to his prolific inventive mind. Perhaps no single patent of John Bell's is more significant of his appreciation of the opportunities for raising the standards of fuel utilization and steam generation than United States Patent No. 1,708,862 recently issued posthumously in his name.

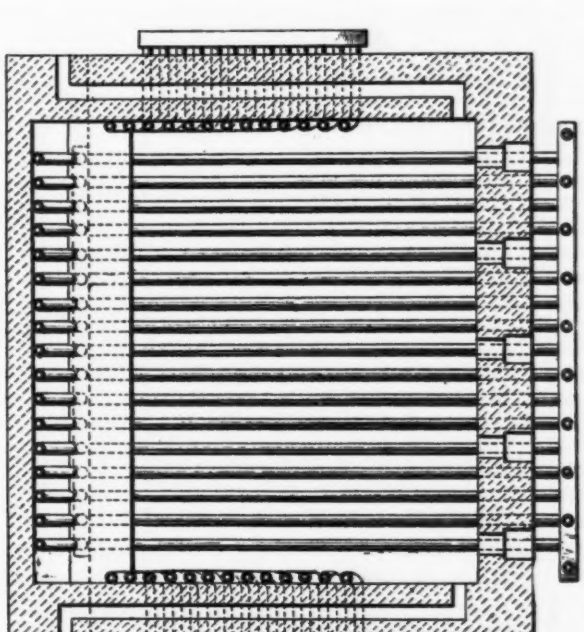
The accompanying illustrations are reproduced from this patent.

The water-cooled furnace walls now so extensively employed in meeting the increased demands of modern steam plant conditions—high rates of fuel burning and steaming capacity and the removal of the limitations of refractory furnaces—almost universally realize the essentials and even the specific constructions which John Bell disclosed and covered in this patent.

He had the unusual faculty of anticipating the needs of the future.



Vertical cross section taken on line 3-3 showing water cooling surface on rear furnace wall.



Cross section on line 4-4 showing bottom water screen.

British Development in Low Heating Value Gas

A Description of the Pioneer Work of George Helps at Nuneaton, England

By DAVID BROWNLIE, London

Mr. Brownlie tells the story of a most interesting experiment with low heating value gas which has been carried on quietly and at times, under difficult circumstances, in the town of Nuneaton, England. The practical results of this work are that since 1927 this town has been using with apparent success a comparatively inexpensive gas of about 200 B.t.u. per cu. ft. What the ultimate significance of this development will be to the manufactured gas industry in England and other parts of the world remains to be seen, but the results to date would seem to indicate at least a possibility of far-reaching and perhaps revolutionary changes not only in the manufactured gas industry but in the coal, oil and natural gas industries as well.

ONE of the most important advances in the entire field of combustion is represented by the fact that the town of Nuneaton has been supplied, with great success, since about 1927, with low grade gas of from 180 to 200 B.t.u. per cu. ft. This is due to the epoch-making scientific researches of George Helps, the engineer and manager of the Nuneaton Gas Company, which have continued for over 25 years past, particularly on the nature of flame, the design and operation of gas burners, and the combustion of low grade gas.

As a result Nuneaton is the only town in the world operating with cheap low grade gas of this character and is also the only town to be supplied entirely with a manufactured gas made by low temperature carbonization methods only.

As is well known, the manufactured gas industry almost invariably sells for domestic use an expensive rich gas of from 400 to 600 B.t.u. per cu. ft., a common figure in the United States being say 500 to 530 B.t.u., although there is a relatively small number of gas undertakings which make a total gasification gas from coal of about 350 B.t.u. per cu. ft. Generally, however, when water gas of 300 B.t.u. per cu. ft., or other similar gas, is manufactured for domestic supply it is immediately carburetted, at great trouble and expense, with heavy oil products to raise the heating value to the 400 to 600 B.t.u. figure. This is well illustrated by the fact that in the United States the manufactured gas industry turns out the gigantic figure of about 250,000,000,000 cu. ft of water gas per annum, almost all of which is carburetted, the total production of American manufactured gas being about 525,000,000,000 cu. ft. per annum, including mixed coke oven gas, natural gas, reformed natural gas, liquid butane, and other products.

Similarly in Great Britain, with a total output of about 320,000,000,000 cu. ft. of gas per annum, as well as in Germany, France, Canada, Australia, and Belgium, the gas supply is always of the rich 400 to 600 B.t.u. variety with the exception of a small proportion of the 350 B.t.u. total gasification gas from coal. These conditions have obtained since the manufactured gas industry originated as a commercial proposition in London about 120 years ago.

The gist of all the work of George Helps is the complete proof, as a result of both scientific research and large scale experience, that such rich gas is entirely unnecessary for domestic supply. Instead there can be used, with equal success, retaining the existing mains and other accessories and only making a slight alteration in the pressure and the burners, an extremely cheap low grade gas of from 180 to 200 B.t.u. per cu. ft.

This constitutes a complete revolution in manufactured gas supply, far ahead of the work of well known total gasification pioneers such as Strache, Dellwik, Kramers, Aarts, Tully, and Vivian B. Lewis, since a 180 to 200 B.t.u. product can of course be made at very much less cost per heat unit, in most cases about a third, as compared with a 400 to 600 B.t.u. gas.

Certainly in my opinion the advance is as important in the history of gas as the supplanting of the cast iron retort by the refractory retort, the invention of gaseous firing of retort settings, and the Welsbach incandescent mantle, while the work on flame is probably the most important since the days of Sir Humphrey Davy.

Particularly interesting also for American conditions, with the severe and rapidly growing competition of natural gas with manufactured gas and an enormous increase in high pressure, long distance gas transmission, is the contention of George

Helps that in general 180 to 200 B.t.u. gas can be supplied in bulk at the same price per heat unit as the original raw coal. Consequently, in many areas it would be commercially practicable to supply such gas in direct competition with raw coal for all kinds of industrial furnace work including steam boiler plants of small and medium size, a development which would be quite impossible with the present rich gas.

Thus in London an average price of rich 400 to 600 B.t.u. gas is 90 cents per 1,000 cu. ft. with coal at say $6 per ton at the gas works and $10.80 per ton for domestic coal, and Helps states that low grade 180 to 200 B.t.u. gas can be sold with profit at only 6 cents per thousand cu. ft., or about the same price per available heat unit as the raw coal.

The small manufacturing and country town of Nuneaton is in Warwickshire, the center of a coal producing area, about 97 miles from London. It has 49,000 inhabitants with 6,000 gas consumers and 49 miles of gas mains, the annual output of 180 to 200 B.t.u. gas being 200,000,000 cu. ft.

Further, the load is almost entirely domestic, only about 19 per cent of the total being for industrial purposes, and the population is fairly scattered,—conditions which are most unfavorable for manufactured gas supply.

In normal average working, approximately 750,000 cu. ft. of gas is produced per 24 hr. and delivered into the mains at a pressure of about 8 in. of water instead of the average pressure of 2 in. of water. Until recently the lowest price was about 24 cents per thousand cu. ft., but just lately, Helps has commenced to sell gas to private houses for complete use instead of coal, that is cooking, water heating, and building heating, lighting being optional, at about the same price per contained heat unit as the raw coal, corresponding to about 6 cents per thousand cu. ft. with coal at $9.00 to $10.00 per ton.

The gas works is situated in the center of the town and has 2 gasholders of a total capacity of 270,000 cu. ft. The extra pressure required is obtained by a small gas booster driven by a 5 hp. electric motor which deals with the whole of the gas supply, and is in fact larger than is needed.

The 180 to 200 B.t.u. gas at the present time is made largely in a "Maclaurin" low temperature carbonization process plant of two retorts, each of ten tons of coal per 24 hr. capacity, which were placed in operation in July 1928. This well known British process consists essentially in the use of a high, vertical continuous retort, something like a small blast furnace, completely filled with the charge, the raw coal being added at the top and the smokeless fuel taken out at short intervals from the bottom. A regulated blast of air is blown in at the lower part of the setting to give partial gasification, and the resulting gases travel up through the descending charge to give progressive low temperature carbonization. The rate of heating is extremely slow with a total duration of treatment of each particle of the charge of about 30 hr.

Normally the "Maclaurin" process gives a gas of about 240 B.t.u. per cu. ft, but Helps reduces this to 180 to 200 B.t.u. by adjusting the air admission. The yield per 24 hr., with a throughput of 20 tons of coal in this time from both retorts, averages 1,000,000 cu. ft. of gas (180 to 200 B.t.u. per cu. ft.), 9 tons (45 per cent) of solid smokeless fuel with 2 to 2½ per cent volatile matter, and 300 to 360 gal. of high-grade low temperature tar, which is essentially a true crude oil having an extremely low pitch content. The ammonia is not recovered and of course scrubbing is not carried out for light oils because of the large volume of gas.

The following represents the average composition of the low grade gas at Nuneaton, in this particular case, however, being 206 B.t.u.—slightly higher than the average. As previously stated, in many cases gas lower than 200 B.t.u. is supplied, and recently the CO_2 content has been reduced to about 6 per cent.

CO	17.4	per cent
H_2	16.0	"
CH_4	10.0	"
Illuminants	0.0	"
Total Combustible	43.4	"
CO_2	10.2	"
O_2	0.4	"
N_2 etc. (by difference)	46.0	"
	100.0	

Total heating value 206.9 B.t.u.

Also there is now installed at Nuneaton a Midland Coal Products process plant which supplies part of the gas. In this case the principle is the combined partial gasification and low temperature carbonization of coal or pitch binder briquettes (mostly non-coking coal) in a vertical continuous retort with regulated air blast but giving a much shorter period of carbonization. The gas is 200 B.t.u. per cu. ft. and coal is used as the raw fuel, the gas being mixed with the "Maclaurin" gas.

It will be clear of course that almost any process of carbonization or gasification can be used so long as 180 to 200 B.t.u. gas of a suitable composition is obtained and Helps for considerable periods used methods such as air mixed with coal gas, and producer gas mixed with coal gas. Until 1917 the Nuneaton Gas Works supplied rich 550 to 600 B.t.u. coal gas on conventional lines using horizontal high temperature carbonization retorts, no water gas being used except on rare occasions because of the nuisance caused in the town.

Helps has been engaged in pioneer work in gas ever since about 1902 being an expert on mains, (he was the first man to weld gas mains direct by oxy-acetylene in the trench), on burners with particular application to illumination, hot-plates and gas cookers of every description, and on total gasification. His researches on the nature of flame commenced about 1902, but it was not until 1918, following upon one of his main British Patents, No. 111495/1916, that the heating value of the Nuneaton Gas Supply was lowered gradually from

550 to 600 B.t.u. to 400 B.t.u., this change being carried out secretly to avoid opposition from the directors of his own company.

At this stage also matters were complicated due to the World War, when conditions made it impossible to spend much money on experimental plant. In order to reduce the heating value to 400 B.t.u., Helps, at that time, merely added air to the straight coal gas. The results were most satisfactory and it was proved by months of large-scale experience that 400 B.t.u. gas gave in the majority of cases just as good results for domestic supply as 500 to 600 B.t.u. with the existing gas appliances. A producer gas generator was then brought into use and the 140 B.t.u. gas employed for diluting instead of air.

Eventually, by 1919, more and more producer gas was added, until 350 B.t.u gas was in regular supply, being reduced to 325 B.t.u. in 1920. Next a total gasification plant was erected for dealing with hard bituminous coal, the intention being to supply the town of Nuneaton direct with 280 B.t.u. gas. Here, however, the same difficulty arose as in the case of the previous water gas plant, that is, smell and fumes during the "blow" period, causing nuisance in the town. As a result the Nuneaton Gas Company was threatened with legal proceedings and had to stop the development. However, in spite of this, and troubles due to coal strikes and lock-outs, the regular practice at Nuneaton became 280 B.t.u. gas, delivered from 1922 to 1926, being a mixture of carburetted producer gas with ordinary straight coal gas of 550 to 600 B.t.u.

Finally, in 1926, Helps made the momentous decision of reducing the heating value of the gas much below 280 B.t.u., and since, by this time he was regarded as stark crazy by many people, secretly, as before, he commenced to reduce the heating value from 280 B.t.u. by 10 B.t.u. at a time, thus confirming his laboratory research work by large-scale experiments, using the gas supply of an entire town and taking all the risks involved.

Many people had the idea, and still have to-day, that low-grade gas, when used for towns supply, will in some mysterious manner, blow up the whole community. However, nothing happened at Nuneaton, and the gas was gradually reduced from 280 to 270, then to 260 B.t.u. and so on, while Helps personally carried out surreptitious investigations throughout the town to make sure that there was no cause for complaint. However, nobody noticed any particular difference in the light, or the use of cookers and other appliances, and the town of Nuneaton—including the Directors of the Gas Company—remained in blissful ignorance for some weeks of the fact that its gas supply, by June 1927, had been reduced from 280 B.t.u. to 200 B.t.u. at which figure it has remained ever since, except, as stated, for successful experimental runs of still lower quality. After this the "Maclaurin" plant was erected in 1928 to supply 200 B.t.u. gas direct in simple fashion, the whole of the horizontal high temperature carbonization retorts being scrapped.

Essentially the scientific basis of this work is that in the ordinary bunsen burner; the mixture of gas and air on the point of actual combustion is about 80 to 90 B.t.u. per cu. ft. Thus, in round figures, one volume of a rich towns gas, 500 B.t.u. per cu. ft., requires five volumes of air for complete combustion, giving a product at the burner of 80 to 85 B.t.u. per cu. ft. If 200 B.t.u. gas is used, one volume requires about 1½ to 2 volumes of air for complete combustion also giving approximately an 80 to 90 B.t.u. product at the burner, the only difference being the extra amount of nitrogen already in the low grade gas added to that from the air for combustion.

Also since Helps supplies the gas at the higher pressure about 8 to 10 in. of water instead of the usual 2 in. of water corresponding to about 6 in. at the burner and modifies slightly the usual design of the burner at the nipple, the result is that with 200 B.t.u. gas one volume takes in about 1½ volumes of air and only say ¼ volume or less is taken for combustion from the surrounding atmosphere, giving a small one-stage flame of a bright blue color. Or, in other words, the gas supply at 8 to 10 in. of water has a highly beneficial pump effect which results in over 80 per cent of the total air being taken in at the air ports of the burner and thoroughly mixed with the gas. But with the present general conditions of manufactured gas supply, that is, a 400 to 600 B.t.u. gas and 2 in. of water, the conditions are entirely different. Generally only 2½ volumes of air per one volume of gas are drawn in at the burner, that is, 50 per cent of the total, and the other 2½ volumes has to be taken from the surrounding atmosphere. Consequently the flame is of the familiar very large, inefficient, two-stage, variety, the inner zone being a stage of incomplete combustion because of lack of air and the reactions only being completed in the outer zone next to the surrounding air where more or less sufficient oxygen is being obtained. For this reason, in practice, most flames of rich 400 to 600 B.t.u. gas result in the escape of unburnt or partially burnt products, such as CO, because, under the average conditions of gas burner operation, there is not sufficient mixing of the rich gas with the air, although in each case the flame temperature is approximately the same for both qualities of gas.

To obtain the same output of heat at a given burner in unit time it is only necessary to pass more low grade gas through the burner nipple, an easy matter and in this case the cost per heat unit output as much less, because the cost of the gas per heat unit, as stated, is generally only about one third as compared with rich gas.

In his elaborate work on the nature of flame, Helps employed a trained artist who knew nothing about fuel technology to draw the various experimental flames exactly as he saw them. For example, in Fig. 1 is given a reproduction of a number of these original drawings, dated October 6, 1915, showing the effect upon the flame of adding oxygen to the gas. The artist made the drawing of each flame in turn, while Helps wrote his ob-

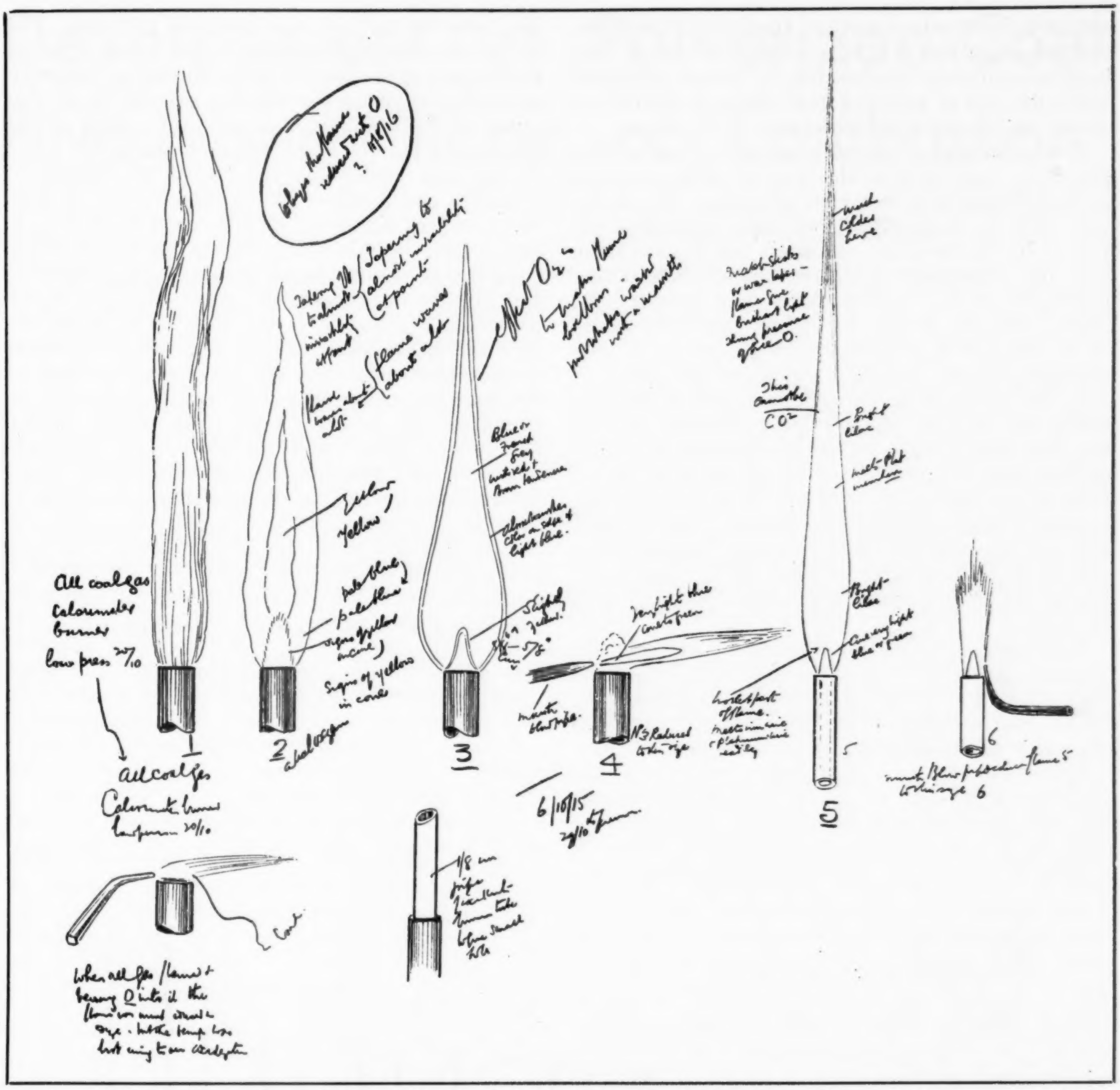


Fig. 1—Original drawings by George Helps dated October 6, 1915 showing the effect upon a gas flame of adding oxygen to the gas.

servations at the time. On the left, No. 1, is a more or less luminous flame of 500 B.t.u. straight coal gas, burning merely at the open end of a tube. No. 2, is the flame given when a small amount of oxygen is added to the gas, while the third drawing, No. 3, shows the same type of flame with more oxygen. No. 5, represents the flame obtained when excess oxygen is present, that is, blown out with free oxygen on the outside, as shown for example by the immediate and brilliant lighting of a matchstick when made to touch the sheath.

As indicated, Helps shows in this way that the nature of the flame changes completely from a large luminous, flickering, two-stage flame, with ordinary incomplete combustion, to a small flame with an inner luminous cone of partially burnt gas, and then to a practically homogeneous, nonluminous, coneless or one-stage flame, representing complete combustion, without the flame having to take any appreciable amount of air from the surrounding atmosphere.

As already stated, most flames, such as for example coal gas and those given by an oil lamp or candle under normal conditions, are operating on the two-stage or cone principle, that is on the lines described, with an inner reducing section of partial or incomplete combustion and an outer oxidizing section with more or less complete combustion, due to the inefficient admixture of air with the combustible products, the flame being of maximum size because of its having to take sufficient oxygen from the air.

But if sufficient oxygen or air is mixed beforehand with the gas to give complete combustion without regard to the surrounding atmosphere, then the flame immediately becomes extremely small in size and is on the efficient one-stage or coneless principle without an inner reducing or in-

complete combustion section. Obviously, therefore, the one-stage flame is very efficient, even if only because complete combustion is always obtained while the loss of heat per unit of gas burned is reduced, due to the smaller volume of the flame.

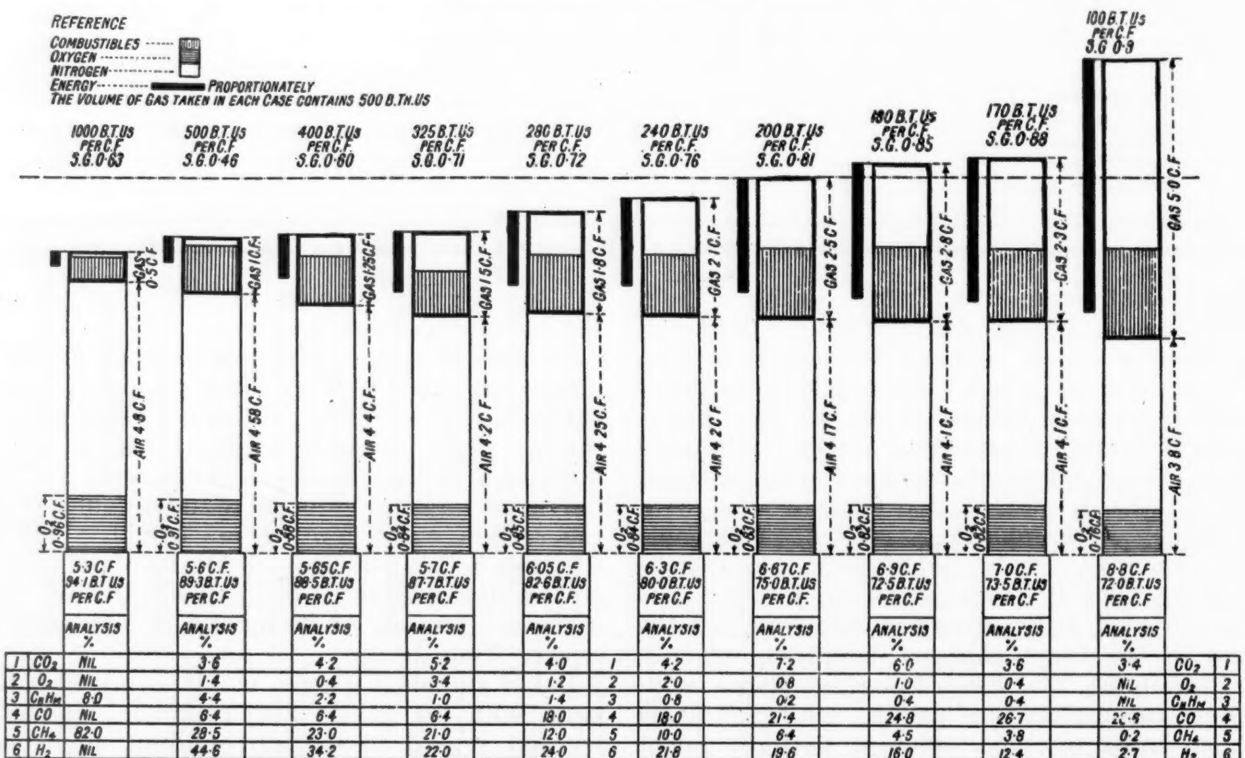
It was because of the original researches of this character, especially in the way of adding oxygen in known amounts to a rich gas flame, that Helps was able to understand the basic principles involved in the burning of cheap 180 to 200 B.t.u. gas, and to predict, contrary to the whole of the principles of the manufactured gas industry for over a century, that a gas of this character would be as efficient in practice under proper conditions of supply as the ordinary expensive rich gas.

It was from these experiments that Helps definitely realized for the first time, contrary also to the universal opinion of the manufactured gas industry, that nitrogen and other inerts in gas make little or no difference, and are in fact under the average circumstances of an ordinary simple Bunsen burner, actually an advantage, because they enable the combustible portion of the gas to be brought into more rapid and intimate contact with the air.

Obviously, therefore, no practical obstacle exists as regards the efficient use of very low-grade gas such as 180 to 200 B.t.u. even when mixed with 50 per cent nitrogen, since this does not affect the efficiency of combustion to any practical extent.

Helps also drew up the highly interesting diagram reproduced in Fig. 2 showing the conditions for ten different industrial gases, of which the analysis is given at the bottom, varying from 100 to 1,000 B.t.u. per cu. ft., and with a nitrogen content between 10.0 per cent and 65.4 per cent. The whole situation with regard to the combustion of these gases at the burner tip is illustrated diagrammatically, showing the relative proportion at this point of the combustibles, nitrogen—both of the gas and in the air, and oxygen when on the point of burning under the theoretical conditions of complete combustion. Thus 200 B.t.u. gas with 44.4 per cent nitrogen, 7.2 per cent CO_2 and a sp. gr. of 0.81, is 75.0 B.t.u. per cu. ft. when mixed with the total amount of air necessary. Similarly rich 500 B.t.u. gas with 11.0 per cent nitrogen, 3.6 per cent CO_2, and a sp. gr. of 0.46, after mixing with the theoretical amount of air forms a product for combustion of 89.3 B.t.u. per cu. ft. That is, the complete range of gases, differing to such an extent as 100 to 1,000 B.t.u., only varies within 72.0 to 94.1 B.t.u., the latter being 1,000 B.t.u. gas when on the point of actual combustion under theoretically perfect conditions. Or in other words, there is in practice almost no difference with the results obtained with the 100 or 1,000 B.t.u. gas, providing of course the conditions are adjusted on proper lines for the addition of air, while in practice, with most types of burners, lower-grade gas actually gives better results because combustion is practically complete, due to the one-stage flame, which is extremely difficult to obtain with rich gas even when using very high pressures.

Finally, in writing this contribution I have to express my sincere thanks to Mr. George Helps for always allowing me full access to the records of his work, and to Mr. Norman Swindin who has made a detailed study of the whole of the principles involved.



		5·3 C.F 94·1 B.T.Us PER C.F	5·6 C.F 89·3 B.T.Us PER C.F	5·65 C.F 88·5 B.T.Us PER C.F	5·7 C.F 87·7 B.T.Us PER C.F	6·05 C.F 82·6 B.T.Us PER C.F.		6·3 C.F 80·0 B.T.Us PER C.F	6·67 C.F 75·0 B.T.Us PER C.F.	6·9 C.F 72·5 B.T.Us PER C.F	7·0 C.F 73·5 B.T.Us PER C.F	8·8 C.F 72·0 B.T.Us PER C.F		
		ANALYSIS %	ANALYSIS %	ANALYSIS %	ANALYSIS %	ANALYSIS %		ANALYSIS %	ANALYSIS %	ANALYSIS %	ANALYSIS %	ANALYSIS %		
1	CO_2	NIL	3·6	4·2	5·2	4·0	1	4·2	7·2	6·0	3·6	3·4	CO_2	1
2	O_2	NIL	1·4	0·4	3·4	1·2	2	2·0	0·8	1·0	0·4	NIL	O_2	2
3	C_nH_m	8·0	4·4	2·2	1·0	1·4	3	0·8	0·2	0·4	0·4	NIL	C_nH_m	3
4	CO	NIL	6·4	6·4	6·4	18·0	4	18·0	21·4	24·8	26·7	[illegible]	CO	4
5	CH_4	82·0	28·5	23·0	21·0	12·0	5	10·0	6·4	4·5	3·8	0·2	CH_4	5
6	H_2	NIL	44·6	34·2	22·0	24·0	6	21·8	19·6	16·0	12·4	2·7	H_2	6
7	N_2	10·0	11·1	29·6	41·0	39·4	7	43·2	44·4	47·3	52·7	65·1	N_2	7

Fig. 2—Diagrammatic illustration by George Helps of the conditions at the burner tip when using 10 different industrial gases, 10 to 1000 B.t.u. per cubic foot, under the theoretical conditions of complete combustion.

Development of Pulverized-Coal Firing and Study of Combustion*

By HENRY KREISINGER
Combustion Engineering Corporation
New York

This paper, presented before the A.S.M.E. Fuels Division meeting in Chicago, February 10 to 13, reviews briefly the development of burning pulverized coal under steam boilers. The author points out the difficulties experienced in the early installations and how some of these difficulties were overcome by changes in the design of furnaces and burners and also by the adoption of more advantageous methods of firing. He discusses the present practice in rates of combustion in furnaces of various designs and the factors that set the limitations. A large part of the paper is devoted to a detailed study of combustion of pulverized coal.

•

THE early installations of powdered coal under steam boilers had furnaces with solid refractory walls. Many of these installations were boilers changed over to powdered coal from stoker firing, and the same design of furnace walls had been used as was then the practice with stoker furnaces. Even the new installations were set with refractory furnaces, although the larger units had the air-cooled hollow-wall construction with the refractory tied to the steel frame for stability.

Some of the first installations were short lived. The furnaces were small, and the refractory walls were rapidly destroyed by erosion of molten ash and by flame impingement. It was this rapid destruction of the furnace walls that held back the application of powdered-coal firing to steam boilers. It became evident that the furnaces must be made large in order to reduce the impingement of flames and to avoid the rapid wasting away of the furnace walls. Large furnaces really meant the removal of the refractory walls from the flame, and giving the flame more elbow room.

The desirability of avoiding impingement of flame against furnace walls made it necessary to employ methods of firing with limited turbulence in the furnace and to admit air in sheets between the flame and the furnace walls. The fact that a large part of the air was introduced into the furnace along the walls resulted in slow mixing and long flame. When higher ratings were required, it was necessary to admit into the furnace a greater excess of air to lower the furnace temperature and thereby reduce the slagging of the ash and the washing away of the furnace-wall refractories.

The removal of the refuse deposited at the bottom of the furnace was another problem in the early installations. The refuse was either fused or became sticky and could not be removed without shutting down the boiler and cooling the furnace. Resort was generally made to large excess air to lower the furnace temperature and to avoid the fusion of the refuse and make its removal easier.

Water-Cooled Furnaces

Greater excess air increased the stack losses and lowered the overall efficiency of the steam generating unit. Therefore, efforts were exerted to reduce the furnace temperature by placing water-cooled surfaces in the furnace. The water-cooled surfaces were placed first over the bottom of the furnace, then over the rear wall, and then by several successive steps over the side walls and the front wall.

With water-cooled furnaces it was not necessary to introduce excess air into the furnace beyond that amount needed for nearly complete combustion, in order to lower the furnace temperature and to avoid slagging of the ash. The lowering of temperature was much more usefully accomplished by allowing the water-cooled walls to absorb part of the heat liberated by combustion. At present practically all large steam-generating units are built with water-cooled furnaces.

The water-cooled walls either replace refractory walls or supply protection to the refractories. Thus, the modern water-cooled furnace makes possible the realization of higher rates of combustion without large excess air, thereby maintaining high efficiency.

The development of water-cooled furnaces removed the limitations to the turbulence in the furnace, and brought about the application of methods of firing with very intensive mixing and more rapid combustion. Impingement of the burning mixture against the furnace walls ceased to be destructive because there were either no refractories to be washed away or because what refractories were used were protected by water-cooled tubes.

* Presented at the National Meeting of the A.S.M.E. Fuels Division, Chicago, Ill., February 10 to 13, 1931.

Intensive mixing or turbulence fills the furnace space more completely with the burning mixture, so that the furnace volume is more fully utilized in the combustion of coal, which results in higher average rate of heat liberation.

Methods of Firing

Three general methods of firing pulverized coal have been developed; namely, the vertical, the horizontal, and the tangential. The vertical firing was the first to meet with a definite commercial success. It was followed shortly by the horizontal firing. Various modifications and combinations of the two methods were devised and put in service. The Gilbert Station of the New Jersey Power and Light Company is an example of a modified horizontal firing. In this installation rows of horizontal burners are placed in opposite walls of the furnaces so that the streams of burning mixture impinge on each other in the middle of the furnace, producing intensive mixing and quick combustion. This modification of the horizontal firing was given the name of opposed firing.

A noted combination of the two methods of firing is used at the East River Plant of the New York Edison Company. Vertical burners firing downward are placed, as usual, in the arches. A set of horizontal burners is placed in the front walls close to the arches. The streams of the mixture of air and coal from the horizontal burners impinge against the streams of air and coal from the vertical burners. The impingement takes place close to the burners and results in quick ignition and intensive mixing. This method of firing has been adopted because at this plant low-volatile Eastern coal is burned which is slow to ignite by straight vertical or horizontal firing. Such combination of firing should be especially useful for burning anthracite coal and coke, which fuels have low volatile matter content and are difficult to ignite when burned in pulverized form. However, on account of the high temperature close to the arch produced by the quick ignition, the arch and front wall should be water cooled to prevent their destruction.

In the tangential method of firing the principle of producing intensive mixing by impingement is carried to the limit. Four sets of burners are placed in nearly the same horizontal plane, one set in each corner of the furnace, the streams of coal and air from each set being directed into the furnace tangent to a circle having a diameter ¼ to ½ of the sides of the furnace. Generally 20 to 50 per cent of the air needed for combustion is supplied with the coal as primary air; the remainder of the air is supplied through the burner around the coal nozzle as secondary air and is forced into the furnace in the same direction as the mixture of primary air and coal.

The streams of mixture of coal and air from the burners in adjacent corners meet at right-angles, and the jets from the diagonal corners move nearly in opposite direction. The impingement of the streams against one another produces a very intensive mixing or turbulence. Due to the fact that the jets are tangent to a circle, the burning mixture is given a rotative motion on its way through the furnace and completely fills the combustion space. Thus, all combustion space is utilized in the burning of the coal, and high average rates of heat liberation are possible.

However, on account of the impingement of the burning mixture against the furnace walls, the tangential method of firing is applicable only to a completely water-cooled furnace. A refractory furnace would not long stand the impingement and the maintenance and outage of the furnace would be high.

There are now several large installations using the tangential method of firing. Among these are two units at the Kips Bay Station of the New York Steam Corporation, having a capacity of 450,000 and 800,000 lb. of steam; three units at the Hell Gate Station of the New York Edison Company, with a capacity of 400,000 lb. each, and two 1400-lb. pressure units at the Fordson Plant with a maximum capacity of 700,000 lb. There are also a number of smaller installations with this method of firing.

Although the corner location of the burners makes it a comparatively easy mechanical problem to fit the burners to a completely water-cooled furnace, the coal-pipe system is somewhat complicated. This is especially true with the direct-firing method where the coal from the mill must be divided into two to four streams which must be piped to different corners of the furnace. To simplify the coal piping and still retain most of the mixing advantages of the tangential firing, a few installations were made with one large burner placed in the bottom of the furnace. The mixture of coal and air is given rotary motion as it is forced up into the furnace from the burner. Although these installations give in general satisfactory results, the combustion is not as rapid as it is with the tangential method of firing. The rotative motion of the burning mixture, completely filling the furnace, is there, but the impingement of a number of streams against one another giving intensive mixing is lacking. When streams of secondary air are admitted through the corners and made to impinge on the rotating mixture from the burner, the results obtained are very near those obtained with the tangential method of firing.

Rates of Heat Liberation

The past experience has demonstrated the best practice for the rate of heat liberation for any furnace design. A few years ago there was a hope for high rates of heat liberation per cubic foot of available combustion space. Predictions were made that the rates of heat liberation would go to or even exceed 100,000 B.t.u. But this hope has not been realized, and it looks as though we are farther than ever from such realization.

At present a good engineering practice is to design refractory furnaces for rates of heat liberation not exceeding 20,000 B.t.u. for continuous opera-

tion, and if the ash is fusible, the rates generally do not exceed 15,000 B.t.u. With water-cooled furnaces the rates of heat liberation are limited to 30,000 B.t.u. for continuous operation, with a peak rate of 35,000 B.t.u. Higher rates are the exceptions and require extra good coal and fine pulverization.

The limit to the rate of heat liberation in refractory furnaces is the excessive erosion of the refractories by molten ash resulting in high furnace maintenance and difficulty in removing the refuse from the furnace. In water-cooled furnaces the limit is generally the deposition of slag on boiler tubes and the clogging of the gas passages through the boiler. Losses from incomplete combustion in many cases are not a serious limitation. With intensive mixing coal could be burned at considerably higher rates before the economic limits due to incomplete combustion would be reached.

Fineness of Coal

Finely pulverized coal burns quicker than coarse coal. Also high-volatile coal ignites and burns quicker than high fixed-carbon coal. There is no need pulverizing coal to a fineness that will give nearly complete combustion at a rate of heat liberation of 40,000 B.t.u. when the construction of the furnace and the fusion of the ash permit a rate of only 15,000 B.t.u. There is no need pulverizing Illinois coal or Texas lignite as fine as the high fixed-carbon Eastern bituminous coals or anthracite. A large part of the combustible of the Illinois coal and Texas lignite burns as gas, which can be burned quickly, whereas most of the combustible in the Eastern coal and anthracite burns as coke or fixed carbon, which burns slowly.

In addition to the relative contents of volatile matter and fixed carbon the various coals behave differently when heated. The particles of anthracite retain their shape and do not stick together when they collide. The Eastern bituminous coals fuse and become sticky. While passing through the stage of fusion, they change their shape, and when two or more particles collide, they may fuse into large pieces. The Illinois coal does not generally change shape and does not become sticky. The individual particles stay separate until completely burned. The lignite and the Western sub-bituminous coals crack and disintegrate. The particles break up into a larger number of smaller pieces, which burn more quickly than the larger particles. When sub-bituminous and lignite coals are burned in pulverized form, it is comparatively easy to reduce the combustible in flue dust to 1 or 2 per cent. On the other hand, it is considered good combustion when the flue dust from burning Eastern high fixed carbon bituminous coal contains 20 per cent combustible. The flue dust from anthracite coal-burning installation often contains 50 per cent combustible.

Therefore the fineness of pulverization should to a large extent be determined by the nature of the coal. Table 1 gives the fineness for the various coals for the best economic results, considering the cost of pulverization as well as the losses from incomplete combustion.

Process of Combustion of Pulverized Coal

The early experiments with powdered coal have shown that intensive mixing produced quicker and more complete combustion. Since then designers of pulverized-coal equipment strove to devise methods of firing and to design burners that would produce intensive mixing in the furnace and quick combustion. A closer study of the process of combustion shows the advantage of intensive mixing.

TABLE 1 ECONOMIC FINENESS FOR VARIOUS COALS

	200 mesh	100 mesh	50 mesh
Anthracite	85	97	100
Eastern low volatile	75	92	98
Eastern high volatile	65	85	97
Illinois	55	80	92
Sub-bituminous	45	75	90
Lignites	35	65	88

Pulverized coal is supplied to the furnace in a mixture with air. The coal particles are heated largely by radiation from the flame of the already burning coal. The heating drives off the volatile matter as gas, and when this gas has been heated to a temperature of about 1100 deg. fahr., it bursts into flame and burns with the oxygen immediately surrounding it. The heat liberated by this combus-

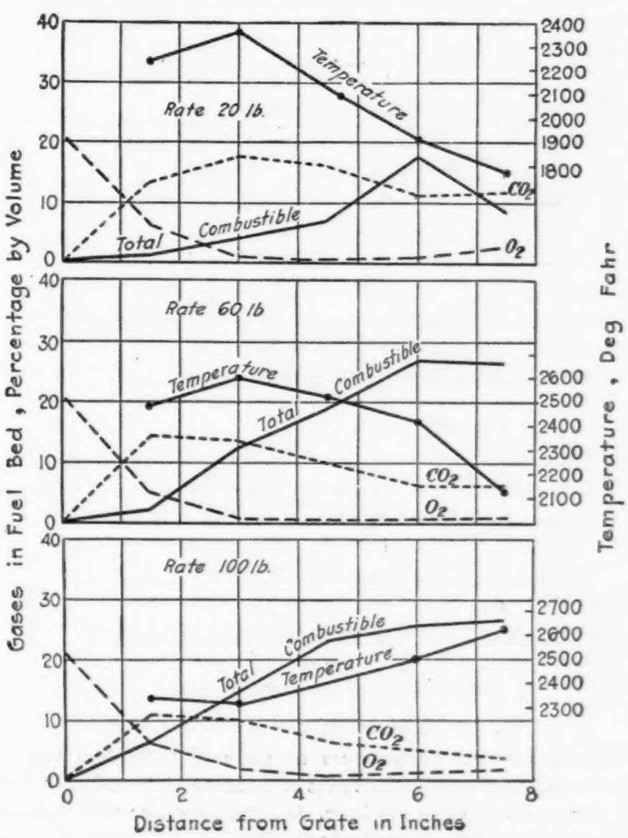


Fig. 1 Combustion of Anthracite in Fuel Bed

(Composition and temperature of gases in 6-in. fuel bed of anthracite coal. Rates of combustion 20, 60, and 100 lb. per sq. ft. of grate per hour. Oxygen combines with carbon as fast as it is brought in contact with it. Practically all free oxygen combines with carbon in the first 3 in. of the fuel bed.)

tion further raises the temperature of the coal particles and speeds up the distillation of volatile matter. The distilled volatile matter ignites and burns first; when most of the volatile matter has been distilled and burned, the fixed carbon begins to burn.

Combustion of fuels in boiler furnaces is a chain of two consecutive processes. The first link of this chain is the coming of oxygen and combustible in contact. The second process or link in the chain is the chemical combination of the oxygen with the combustible when they have made contact. The speed of combustion is always controlled by the slower of the two links of the chain. The process of bringing oxygen and combustible in contact is by far the slower of the two links. Time is required for the oxygen and combustible to make contact. Once brought in contact the chemical combination at the ordinary furnace temperature is virtually instantaneous. In other words, the combustible can be burned only as fast as oxygen is brought in contact with it.

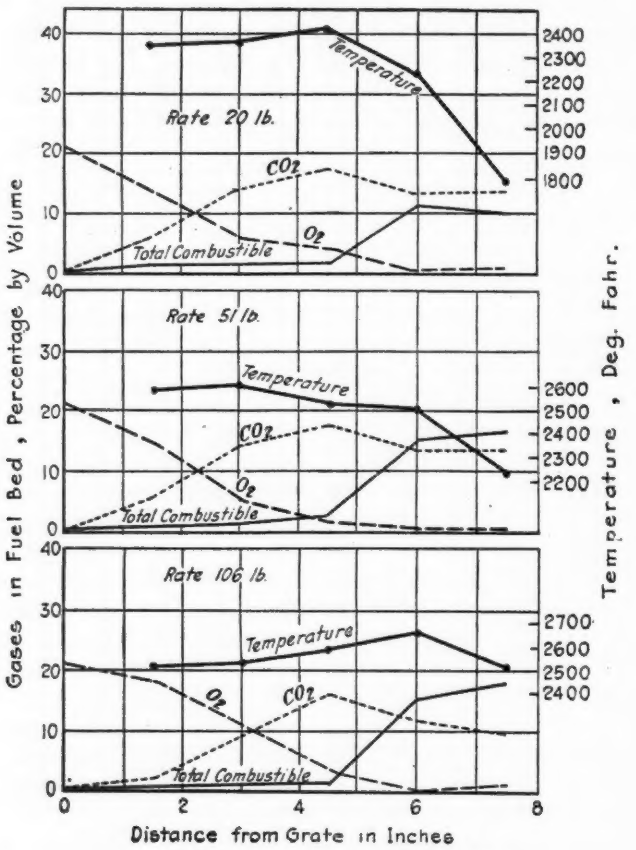


Fig. 2 Combustion of Coke in Fuel Bed

(Composition and temperature of gases in 6-in. fuel bed of coke from Pittsburgh coal. Rates of combustion 20, 51, and 106 lb. per sq. ft. of grate per hour. Oxygen combines with coke as fast as it is brought in contact with it.)

This principle is fully utilized in controlling the rate of combustion on grates. The more air that is forced through the fuel bed, the faster the oxygen makes contact with the combustible and the higher is the rate of combustion. During its passage through the spaces between the pieces of fuel, the oxygen comes in contact with the combustible and combine with it as fast as the contacts are made. The limit is reached only when the flow of air through the fuel bed becomes so great that the pieces of fuel are lifted and blown away and holes or craters are formed in the fuel bed. With some fuel it is possible for the rate of combustion or gasification to greatly exceed 100 pounds of fuel per hour per square foot of grate before this limit is reached.

Several years ago the Bureau of Mines made a series of experiments, the results of which demonstrated the foregoing principle. These results have been published in Technical Paper No. 137. Figs. 1 and 2 are reproduced from this publication. They show the composition of the gases at various distances from the grate and how quickly oxygen combines with combustible.[2]

When fuel is burned in pulverized form, the combustible burns only when it comes in contact with free oxygen, and therefore burns only as fast as it makes contact with oxygen. The distilled volatile combustible being in gaseous state diffuses into the atmosphere immediately surrounding the coal particles, meets the free oxygen, and burns. In other words, it goes halfway to meet the free oxygen and therefore makes contact with it quickly. The fixed carbon on the other hand stays in the coke residue in solid state and must wait until free oxygen works its way to it and makes contact with it.

A particle of pulverized coal is highly concentrated combustible which requires for its complete combustion a large volume of air many times as great as its own volume. Even if the mixture were perfectly uniform—that is, if the particles of coal were so spaced that all the air needed for the complete combustion surrounded each particle in a sphere—a large part of the oxygen molecules would be an appreciable distance from the coal particles, and time would be required to make contact with their surface. In case of gaseous fuels a mixture with air can be obtained in which all the oxygen molecules needed for complete combustion are comparatively near the combustible molecules and contacts between them can be made more quickly than in the case of pulverized coal.

This great concentration of combustible in a particle of pulverized coal and the large volume of air needed for its combustion compared to some of the gaseous fuels is illustrated in Fig. 3. The black dots represent spheres of various combustibles, and the large circles represent spheres whose volumes are equal to the volume of air needed for complete combustion at the furnace temperature of 2000 deg. fahr. Comparison is made with three gaseous fuels; namely, blast-furnace gas, natural gas consisting of methane, and a gas called hexane. The gas hexane is used in the illustration to show the effect of more concentrated fuel on the air requirements and the necessity of mixing. Actually hex-

[2] A more detailed study of this subject is given in a paper, "Burning Characteristics of Different Coals," by the present author and B. J. Cross in A.S.M.E. Trans., Paper FSP-50-52 (Sept.-Dec., 1928).

ane does not last long in the furnace. It is broken up by the heat into lighter gases and soot. It is assumed for the sake of the illustration that methane and hexane are stable at the furnace temperature and do not break into more simple gases. In the case of the blast-furnace gas only one-third of the gas is combustible CO and H_2; therefore, only one-third of the dot is shown black. The remaining two-thirds are inert gases N_2 and CO_2. The relative volumes and diameters of spheres of the combustibles and the air required for their combustion are also given in Table 2.

TABLE 2. COMPARISON OF AIR REQUIREMENTS FOR BURNING DIFFERENT FUELS

Fuel	Blast-furnace gas	Natural gas	Hexane	Pulverized coal
Composition	33% CO+H_2	100% CH_4	C_6H_{14}	....
Heat value	100 B.t.u. per cu. ft.	1000 B.t.u. per cu. ft.	4500 B.t.u. per cu. ft.	13,500 B.t.u. per lb.
Volume of oxygen per cu. ft. of gas, cu. ft.	0.165	2.0	9.5	(Air per pound of coal) 9.8 lb.
Volume of air per cu. ft. of gas, cu. ft.	0.825	10.0	45.6	Air at 2000° F. (per pound of coal) 46,000 cu. ft.
Diameter of gas sphere	*D*	*D*	*D*	*D* (diameter of coal particle)
Diameter of sphere of air	1.22*D*	2.225*D*	3.6*D*	35.8*D*
B.t.u. per cu. ft. of mixture at 2000° F.	11.8	19.6	20.8	21.2

It is apparent that in the case of the gaseous fuels, in a nearly homogeneous mixture with all the air needed for combustion, the free oxygen is close to the combustible with which it is to make contact. However, with pulverized coal a large part of the oxygen is a considerable distance from the coal particle and more time is required for all the oxygen to make contact with the combustible in the coal particle than in the case of the gaseous fuels. Furthermore, the gaseous fuels can be easily subdivided into very small volumes which in the limit may become individual molecules, in which case the mixture may become completely homogeneous. In such a mixture the oxygen molecules would be close to the molecules of combustible, and contacts between the two would occur rapidly although not instantaneously. On the other hand, there is a limit to the fineness to which coal can be pulverized. The limits are both physical and economical. There are no available means to tear coal into individual molecules. Even within the limits of practical pulverization, very fine particles tend to cling together to form clusters, and thus the benefit of finer pulverization is partly lost. Besides, fine pulverization is costly. The average-sized particle of pulverized coal is very large compared to the size of a molecule of combustible gas, and much more time is required for all the free oxygen needed for complete combustion to come in contact with the combustible of the coal particle.

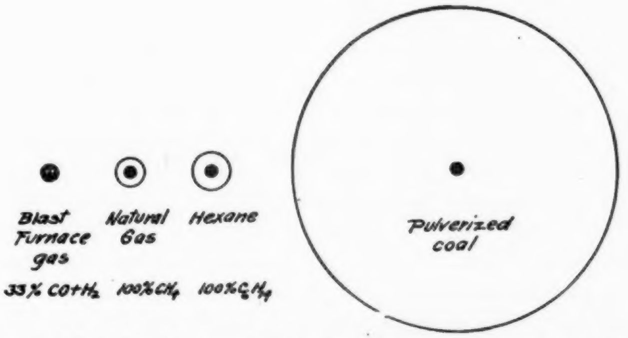


Fig. 3 Relative Volumes of Various Combustibles and the Air Needed for Their Combustion

(The black dots represent spheres of combustible. The outside circles represent spheres whose volume is equal to the air needed for complete combustion of the combustible.)

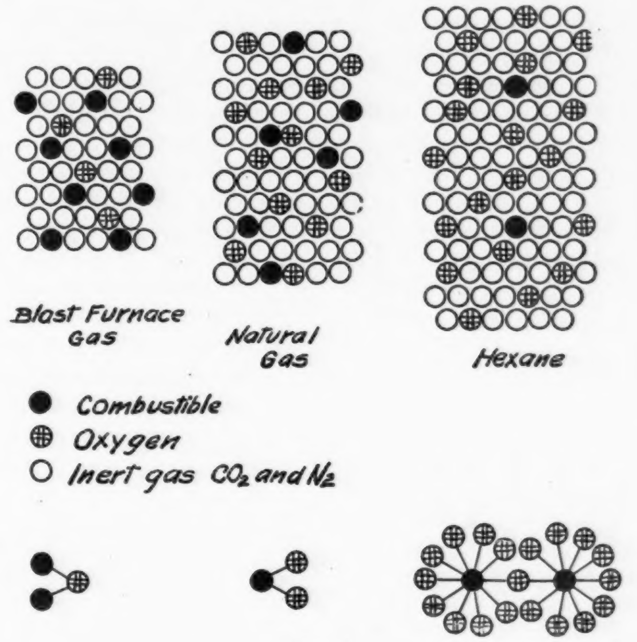


Fig. 4

(At the top are shown cross-sections through three gaseous fuels in a homogeneous mixture with all the air needed for their complete combustion. At the bottom are shown the number of molecules that are to combine with each molecule of the three fuels.)

Although contacts between oxygen and gaseous combustible in a mixture occur comparatively easily, they do not take place instantaneously. Even if the mixture is perfectly homogeneous an appreciable length of time is required for all combustible to make contact with the oxygen. The necessity for the time factor is illustrated in Fig. 4, which shows a section through the mixtures and the probable arrangements of the molecules of the three gaseous fuels in nearly homogeneous mixture with all the air needed for combustion. The shaded circles represent the molecules of the combustible, the cross-section circle represents oxygen molecules, and the white circles the inert gases, nitrogen and, in the case of blast-furnace gas, also carbon dioxide. At the furnace temperature the molecules are in rapid motion and collide frequently with one another. In all three mixtures all the oxygen molecules must make contact with the combustible molecules. Some of the oxygen molecules are close to the combustible molecules, and contacts may occur quickly. Other oxygen molecules are farther away, and must work their way around and between the inert molecules

toward the combustible molecules, and more time elapses before the contacts are made. As the combustible molecules combine with the oxygen, there are fewer active molecules left, and the contacts become less frequent.

In the heavier combustible gases such as methane and hexane, a number of oxygen molecules must make a contact with each combustible molecule, and many of the molecules must come a comparatively long distance to make the contact. This is especially true of hexane. But even with this heavy gas the number of molecules is small and the distance they have to travel short as compared with the combustion of pulverized coal. So large is the number of combustible molecules in a small particle of coal, and so great is the number of oxygen molecules that must make contact with the coal particle that it is impossible to draw a diagram. If the coal particle consists mostly of fixed carbon, all the oxygen molecules must come to the particle of coal to make contact, and the rate of contact making is slow. If the particle is coal with high volatile matter content, the volatile matter leaves the coal particle and diffuses into the air and the rate of contact making is high. It is well known how slowly burning are anthracite and coke in pulverized form, and how difficult it is to reduce the combustible in the flue dust below even 30 per cent.

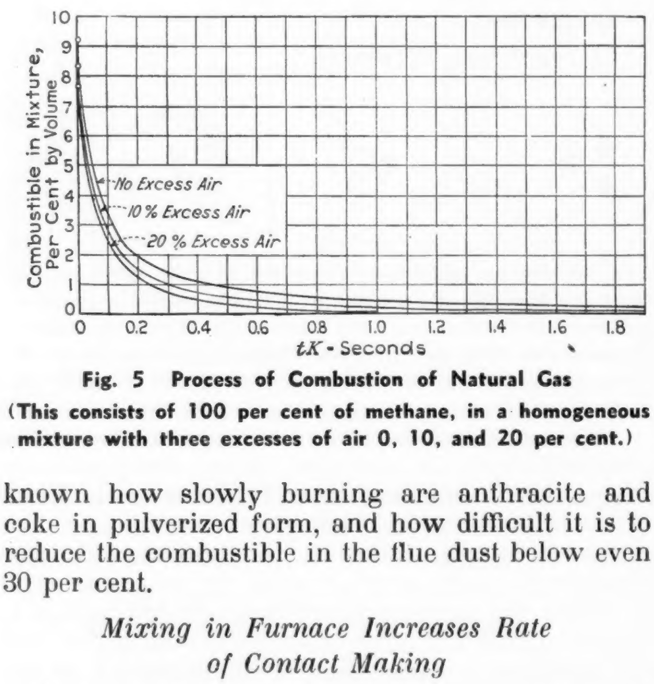


Fig. 5 Process of Combustion of Natural Gas

(This consists of 100 per cent of methane, in a homogeneous mixture with three excesses of air 0, 10, and 20 per cent.)

Mixing in Furnace Increases Rate of Contact Making

Mixing in the furnace greatly increases the rate of contact making. It brings the unused free oxygen molecules next to the surface of the coal particle. It also carries away the products of combustion and the distilled volatile matter from the coal particle, thus equalizing the distribution or concentration of free oxygen and the unburned combustible in the furnace.

It is the mixing in the furnace that brings combustible and free oxygen nearer together so that they can make contact and combine. Mixing outside of the furnace is ineffective in producing rapid combustion. All the devices that were designed for mixing outside of the furnace failed in producing rapid combustion unless the mixing was carried into the furnace. A uniform mixture of pulverized coal and air is very difficult to obtain, and if it is ever obtained it can not be maintained. The coal is much heavier than air and tends to settle out of the mixture. It is kept in suspension by the movement of the mixture. Even during the flow of the mixture the concentration of the coal particles in various parts of the section of the stream is constantly changing. A slight change in the direction of the stream tends to concentrate the coal at the outside curve of the stream.

With intensive mixing, the coal particle moves faster or slower than the air, or moves in different direction. In other words, the coal particle constantly changes its position with respect to the air, moving out of one location where it made contact and used up all the free oxygen near it, into a new location where there is still uncombined oxygen. At the same time it leaves behind the products of combustion either as CO or CO_2, and H_2O. During the distillation process the particles leave behind also most of the distilled gaseous combustible. A careful observer can easily see some of the larger coal particles moving through the furnace with a comet-like tail of burning volatile matter behind them. Mixing continually equalizes the concentration of free oxygen and combustible in all parts of a cross-section of the stream of burning mixture.

Effect of Concentration on the Rate of Contact Making

Even with intensive mixing and the resulting equalization of the concentration of the free oxygen and the combustible, the rate of contact making rapidly decreases as the process of combustion goes on. There are fewer oxygen molecules left; some of the very small particles have burned completely, and the larger ones have smaller surface for the oxygen to make contact with.

In case of a gaseous fuel in a homogeneous mixture with air, each combustible molecule within a given unit volume of this mixture has a chance to make a contact with any of the molecules of oxygen within that unit volume. In other words, the rate at which contacts occur is proportional to the product of the concentrations of the two kinds of molecules. If this concentration is expressed in percentage by volume, then the rate of the contact making is proportional to the products of the percentage of oxygen and the percentage of combustible gas. Thus, if C is the percentage of combustible gas and O the percentage of oxygen, then the rate of contact making $= K(C \times O)$. This is true at any time during the process of combustion as long as the mixture is homogeneous.

If a chemical combination takes place every time a contact between two active molecules occurs, which can be assumed with reasonable certainty, every contact removes one molecule of oxygen and at least part of the molecule of combustible from active participation in the contact making, and also in the process of combustion. The rate of contact making during the process of combustion is then expressed by the equation:

$$\frac{dc}{dt} = K(C \times O) \ldots\ldots\ldots\ldots [1]$$

The oxygen in a furnace consists of two parts; namely, that needed for complete combustion of the combustible, and the excess oxygen that is left after all the combustible has been burned. The first part of oxygen is always proportional to the combustible, and the second part remains constant. We can then write

$$O = ac + b$$

where a and b are constant; b stands for the excess oxygen and a for the number of oxygen molecules required to burn a molecule of combustible. Equation [1] then can be written

$$\frac{dc}{dt} = Kc\,(ac + b) \ldots\ldots\ldots\ldots [2]$$

On integration and the determination of the constant of integration the equation becomes

$$Kt = \frac{1}{b}\log_e\left(\frac{ac + b}{c}\right) - \frac{1}{b}\log_e\left(\frac{ac_1 + b}{c_1}\right) \ldots [3]$$

where c_1 = initial concentration of combustible and t = period of time since process of combustion has started.

With no excess air Equation [3] becomes

$$Kt = \frac{1}{ac} - \frac{1}{ac_1} \ldots\ldots\ldots\ldots [4]$$

For natural gas containing 100 per cent of methane, and burning with 0, 10, and 20 per cent of excess air, the foregoing equations give the three

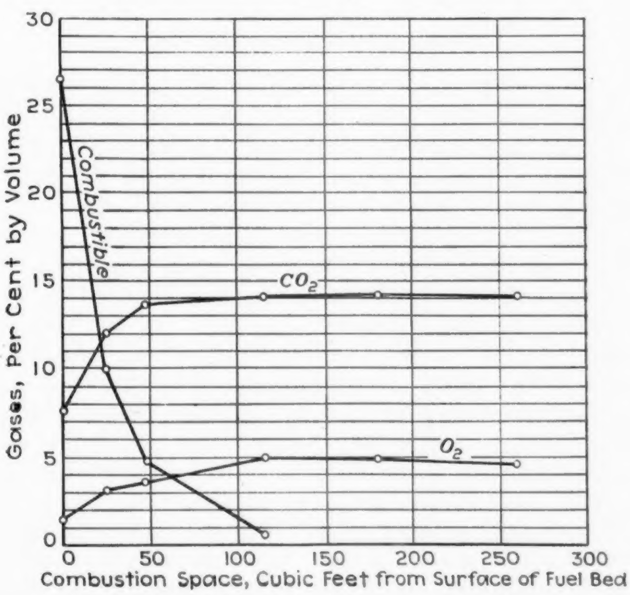


Fig. 6 Process of Combustion of Gaseous Combustible Rising From a Fuel Bed of a Stoker-Fired Furnace

(Air for combustion was supplied through various openings above the fuel bed.)

curves shown in Fig. 5. The curves are plotted with the unburned combustible as ordinates and the time as abscissas.

The curves show two interesting features which are frequently observed in the actual operation of furnaces. The combustible burns at first at high rates, but this rate rapidly decreases as the mixture moves away from the burner, and the rate becomes very low when the combustible has been reduced to 1 per cent. In other words, the first

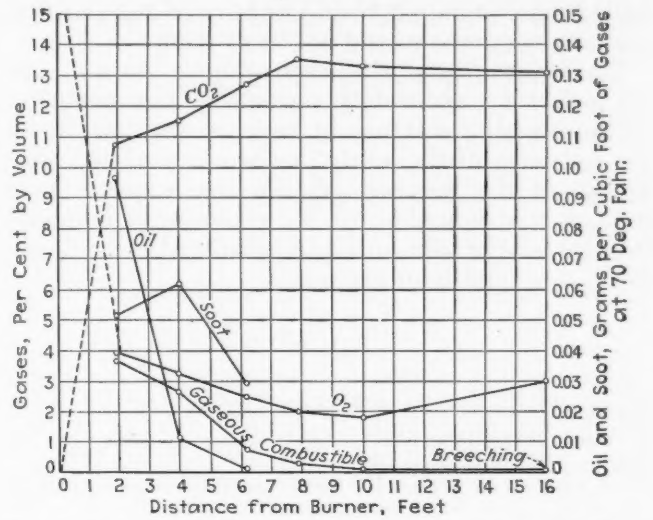


Fig. 7 Process of Combustion of Fuel Oil in a Marine Boiler Furnace

(The atomized oil upon entering the furnace partly burns and partly breaks up into soot and gaseous combustible. About 75 per cent of the combustion occurs within the first 2 ft. distance from the burner.)

6 or 7 per cent of the combustible burns much more quickly than the last 1 per cent. It is the burning of the last 1 per cent of combustible that requires time and furnace volume. Within a practical furnace volume the combustible cannot be burned completely, it can be only reduced to economically insignificant quantity. When gaseous fuels are burned it is often difficult to determine the last small traces of combustible in the furnace gases. We know that with pulverized coal we can never reduce the combustible in flue dust to zero.

The rate of heat liberation during the combustion of the first 6 or 7 per cent of combustible is several times as great as the average rate for the entire furnace.

The excess air does not affect materially the initial rate of combustion. It is very useful, however, in burning the last 1 per cent of combustible. The first 10 per cent of excess air is more effective in burning the last 1 per cent of combustible than subsequent additions to the excess air.

Equations [3] and [4] and the curves are applicable to gaseous fuels with which it is possible to express the concentration of combustible in percentage by volume. In oil burning and the burning of pulverized fuel, other factors would have to be substituted for the concentration of combustible. Such factors might be partly proportional to the number of globules of oil or particles of coal and their surfaces per unit volume; that is, the factor should include the fineness of atomization of oil or of pulverization of coal. Most of the oil volatilizes in the furnace and behaves as heavy gas.

A large part of high-volatile coal also volatilizes and burns as gas. The curves representing the process of combustion of these two fuels when all the air is supplied through or closely around the burner would be very similar to the curves shown in Fig. 5. With anthracite and other low-volatile fuels the combustion would be slower and the first part of the curves would not be so steep.

For experimental studies in which the air supply could be accurately measured, the sampling of the burning mixture at various distances from the burner and the analytical work could be simplified, if the decrease of the free oxygen were used as the indication of the progress of combustion instead of the unburned combustible. Equation [1] would then become

$$\frac{dO}{dt} = KC(O + b)$$

where O is the oxygen necessary to burn completely the combustible C, and b the excess of oxygen. The combustible C is then always proportional to O and can be expressed by the equation $C = aO$.

Equation [1] in its simplest form then becomes

$$\frac{dO}{dt} = KaO(O + b)$$

The curves obtained by this equation would be similar to those of Fig. 5, but would be asymptotic to horizontal lines representing the constant excess of oxygen b. Comparison of these curves with those obtained from experimental results would show to what extent the equation would have to be modified.

Experimental data on the process of combustion in furnaces are meager. Obtaining such data requires special apparatus and much careful work. Figs. 6 and 7 show some experimental results from the work of the Bureau of Mines. Fig. 6 shows the progress of combustion of gaseous combustible rising from the fuel bed of a stoker-fired furnace. The oxygen was supplied by air admitted through various openings over the fuel bed and was not therefore mixed with the combustible gases at the point when they were leaving the fuel bed.

Fig. 7 shows experimental data on the progress of combustion in an oil-fired marine-boiler furnace. This figure indicates how difficult it is to determine the total unburned combustible because part of it is in gaseous state, part in liquid, and part in solid state. It is necessary to use two scales to show its amount. The drop in CO_2 and the rise in O_2 in the breeching is due to leakage into the setting.

The curves of these two figures show a strong resemblance to the curves of Fig. 5. Both of these figures indicate very rapid combustion at the beginning of the process. This is especially true of the oil-burning furnace. Two feet from the mouth of the burner a large part of the combustible was burned, as is indicated by 10.7 per cent of CO_2. In the next six ft. of the distance the CO_2 increased less than 3 per cent.

Conclusions

Intensive mixing in the furnace is the most important factor within the control of the designer and operator for producing rapid combustion.

Mixing outside of the furnace is ineffective in producing rapid combustion because a uniform mixture of air and coal cannot be maintained. Without mixing in the furnace, volatile matter distilled from the coal would hang around the coal particles in spheres with only the outside of the surface of these spheres exposed to the contact of the oxygen molecules.

Mixing in the furnace tends to keep the coal particles uniformly distributed across any section of the stream and makes the atmosphere surrounding the coal particles a homogeneous mixture of gases; in other words, mixing in the furnace constantly equalizes the concentration of free oxygen and unburned combustible over any section of the moving stream of burning mixture.

Combustion constantly destroys equalized concentration; mixing reestablishes it. Beyond such constant equalization of concentration, mixing can have no further effect on the rapidity of combustion. With equalized concentration, combustion proceeds at a definite rate depending on the concentration of the combining substances.

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The Physical Characteristics of Natural Draft Chimneys

(Continued from page 20)

ials used in their construction; pleasing appearance to the eye from an architectural standpoint; can be matched with adjoining or adjacent buildings as to general color; can withstand the corrosive action of gases without serious effects, can be adapted to almost any type of installation; can be wrecked or torn down without great expense; can be built in conjunction with, and bonded to, adjacent buildings; relative low cost for the smaller and average sizes; and relative ease of construction. The chief disadvantages are: apparent inherent tendency to develop cracks when a high temperature difference exists (this tendency can be practically eliminated by using a plentiful supply of steel bands properly placed); mortar joints disintegrate under the action of the corrosive gases only which disadvantage, however, can be reduced to a minimum by substituting fireclay for lime in the mortar; cannot withstand severe earthquake shocks without practically total destruction; become badly damaged when struck by lightning (this condition can be completely eliminated by installing a proper lighting protection system); and comparative great weight.

Despite the apparent disadvantages of radial brick chimneys, the great majority of chimneys built nowadays are of this type and they have given almost complete and universal satisfaction.

Considerations in the Design of the Small Boiler Plant

PART THREE

In this, the third article of his series, Mr. Breslove discusses coal and ash handling equipment, ash disposal, feedwater regulation and treatment, instruments and control apparatus, and piping. The last part of the article considers efficiency in the small plant and its relative importance from the standpoints of capital investment and economics generally . . . The next article, which presents detailed analyses of several typical plants, will conclude the series.

By
JOSEPH BRESLOVE
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HAVING considered the various types of equipment which perform the primary functions of a steam plant, we shall now turn to equipment and methods which apply to what may be termed secondary or collateral functions.

Coal and Ash Handling: In considering the question of coal handling for a small plant many problems of a diverse character present themselves. The very small plant as a rule is located in a basement or the first floor of an industrial building, requiring truck delivery of fuel. In such cases, it is almost always necessary to discharge the coal onto the firing floor from which it is shovelled into the stoker hopper. The quantity of coal used is not great and outside of the dust and inconvenience there would be little advantage in mechanical methods of coal handling.

In the larger plant, using from 8 to 50 tons per day, the question of coal handling is of a different order. Usually, a railroad track is located adjacent to the building and it is a simple problem to discharge the coal into a track hopper, elevate it with a bucket elevator or skip hoist to an overhead bin from which it will flow to the stoker hoppers by gravity. The conventional form of track hopper, feeder, bucket elevator and parabolic steel bunker, with longitudinal screw conveyor over the bunker readily adapts itself to the majority of installations. In some cases, it is desirable to purchase run-of-mine-coal so that a crusher is interposed between the track hopper and the elevator. A steel bunker 15 to 20 ft. in width with a depth varying from 10 to 15 ft. and a capacity of 3 to 5 tons per running foot can be installed with minimum cost and engineering effort. The column supports may be spaced about 20 to 25 ft. and, for a plant of two boilers, this results in a bin having a capacity of about 150 tons. This type of bunker has the advantage of being easily constructed for the accommodation of one or two boilers and it may be increased in length as additional units are added, the initial cost being no greater on this account. In the case of horizontal boilers, it is frequently feasible to extend the front boiler columns making them heavy enough to support half of the bunker load in addition to the boiler load, thus developing a clean-cut firing aisle with a minimum number of columns. An installation of this character is shown in Fig. 1. The column at the front of the boiler takes part of the bunker load as well as its share of the boiler load. Where the units are larger or in greater number and the bunker longer, a belt conveyor with tripper may be substituted for the distributing screw conveyor. Contrary to the sometimes accepted opinion, the steel bunker does not deteriorate appreciably and if it is occasionally painted with a coat of bitumastic paint it will last for many years. Some of these bunkers under the writer's notice have been in service for 10 to 15 years without repairs. A cast-iron bunker may be preferred and there is nothing to be said against this preference except the disadvantage of additional weight and increased cost.

The foregoing type of equipment is readily adaptable to most places and particularly useful in revamping an old plant where either the head room, width of building or other obstructions make a bunker installation a difficult task. Where the power house roof is low, the bunker columns may be extended up through the old roof and form the supporting members of a monitor over the bunker. Frequently, the roof lacks but a few feet of the necessary height in which case the screw conveyor may be installed outside the building, the chutes passing through the roof and discharging into the bunker. The screw conveyor should be weather protected and made accessible from the outside. This is an inexpensive method of obtaining the necessary few feet of additional height.

In Fig. 1, is shown a boiler room which was of

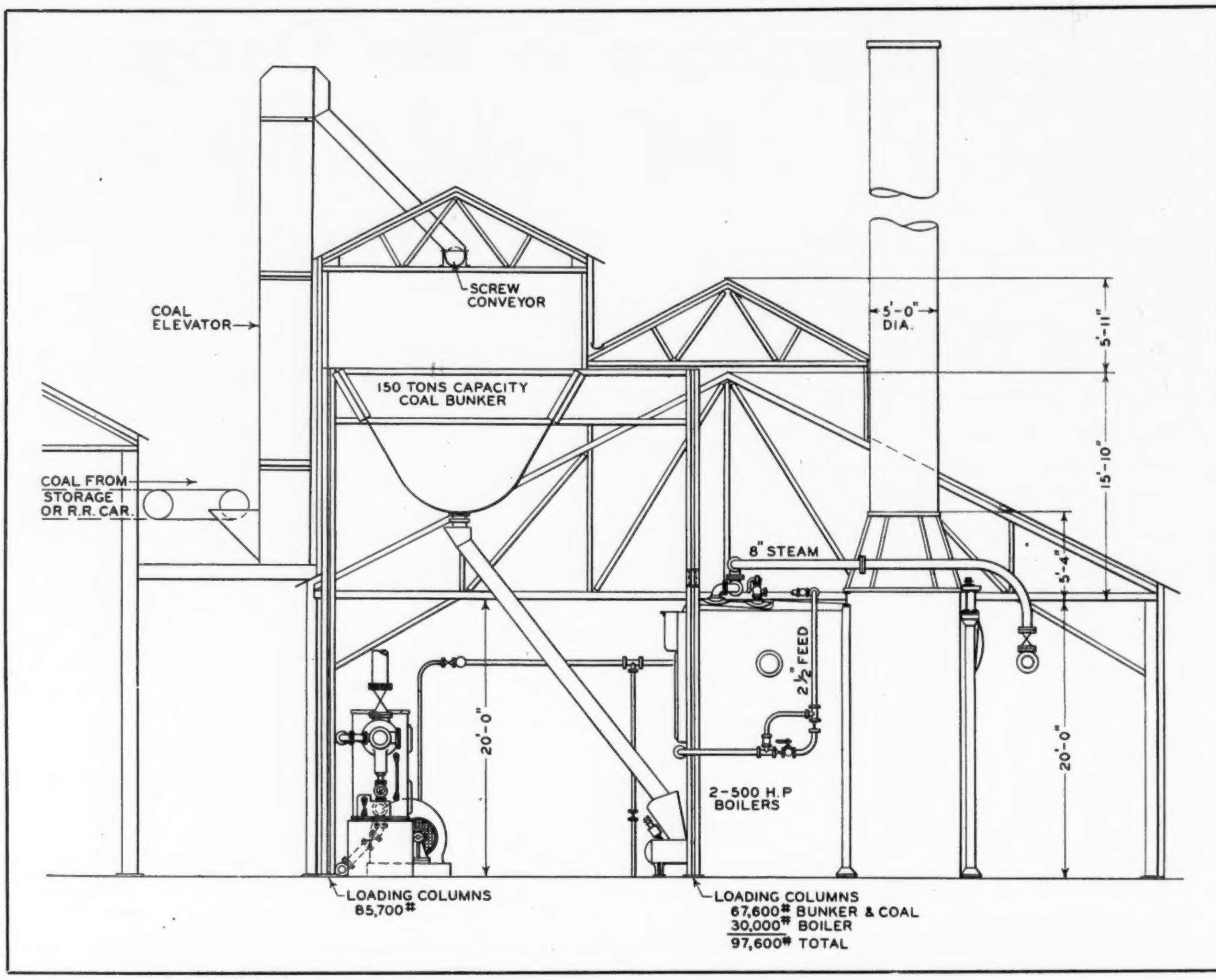


Fig. 1—General arrangement of plant—Pittsburgh Spring & Steel Company.

ample width but insufficient height and the scheme adopted provided for a monitor over the bunker. Fig. 2 shows this bunker during construction. The front boiler columns also carry the bunker girders. It will be noted that coal is taken from a storage yard and conveyed through an adjoining building to the short bucket elevator. Fig. 3 is another layout in which the railroad track is adjacent to the building and coal taken directly from the cars. This is a case where the distributing conveyor is installed outside the boiler house with the discharge chutes passing through the roof. Both these buildings originally housed older type equipment and the problem was to adapt them to the newer elements with a minimum of construction.

Where the plant contains two or more boilers and it is desirable to weigh the coal burned under each, a different arrangement is called for. In the parabolic steel bunker it may take the form of a coal bin at one end of the boiler house, possibly on the outside, and a weigh larry. For this condition several designs of storage bins have been developed, each of which may have special features for the particular installation. They consist essentially of a storage bin loaded from the railroad cars by any of the preceding methods and discharging into the weigh larry which travels on a track over the stoker hoppers into which the coal flows by gravity. It is questionable, however, whether weighing apparatus is justified in most of the smaller plants, and it is rather the exceptional case that warrants it. Where the added expense is justified, it is a convenient form of checking the coal consumption.

It has been the writer's experience, covering a large number of plants, that the form of coal handling equipment described in the preceding paragraphs may be selected without fear of criticism. It is comparatively inexpensive, simple and efficient to install and operate and the maintenance is low.

Ash Disposal: In the small hand-fired boiler house, the time honored method of using the wheelbarrow for disposal of ash on the dump from which it is removed by truck is still very much in evidence, and where the quantity of ash handled is small, this method is probably as good as any. But for the medium size plant, other methods have come into being, the type depending on the local conditions. Probably, the most widely used is some form of steam jet ash conveyor. It has many real advan-

tages. The pipe line conveyor takes up very little room, is low in first cost, simple to operate, has no moving parts and, if properly designed, is practically dustless. The ash bin may be located where it will discharge directly into railroad cars or truck, and yet be a considerable distance from the boilers. In this sense, the steam jet conveyor is flexible and worthy of consideration.

In the earlier stages of its development, the steam jet conveyor was poorly designed and its installation in certain positions was distinctly disadvantageous to its operation. The result was high steam consumption, high maintenance, and a multiplicity of minor ailments. These have been largely overcome and today the pipe line form of conveyor is a fairly reliable piece of equipment. It presents a clean, flexible method of ash disposal. The steam consumption will depend upon the length of line, the number of bends and the time during which the steam valve is open. It will rarely be as low as the optimistic manufacturer believes it to be but if care is taken to have the ash on the floor alongside the conveyor opening ready for ejection as soon as steam is turned on, and if the operating periods are wisely chosen at a time when the boiler has been relieved of some of its regular load, the cost of operation is not objectionable. The steam consumption will vary from 300 to 600 lb. per ton of ash, depending on the layout.

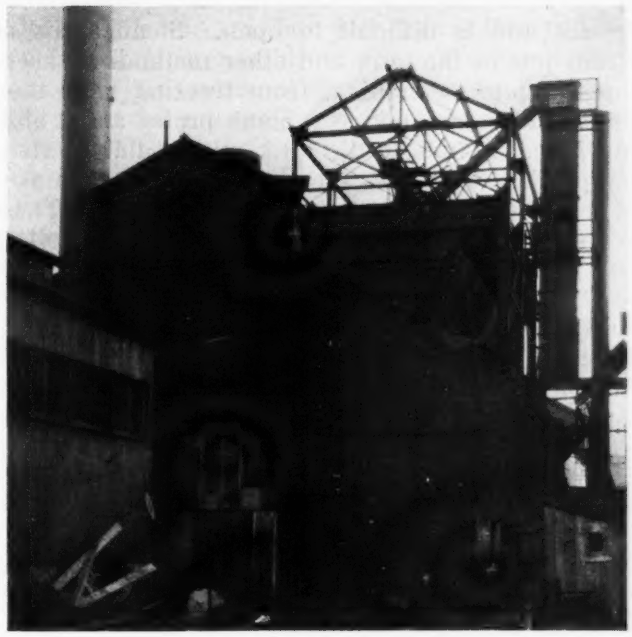


Fig. 2—Plant of Pittsburgh Spring & Steel Company showing structural steel and coal bunker.

The difficulties encountered with the steam jet conveyor are mostly in the ash tank where in Winter the condensed steam freezes. The ash packs tightly and is difficult to remove. The ash gate, which is usually of the clam shell type, also

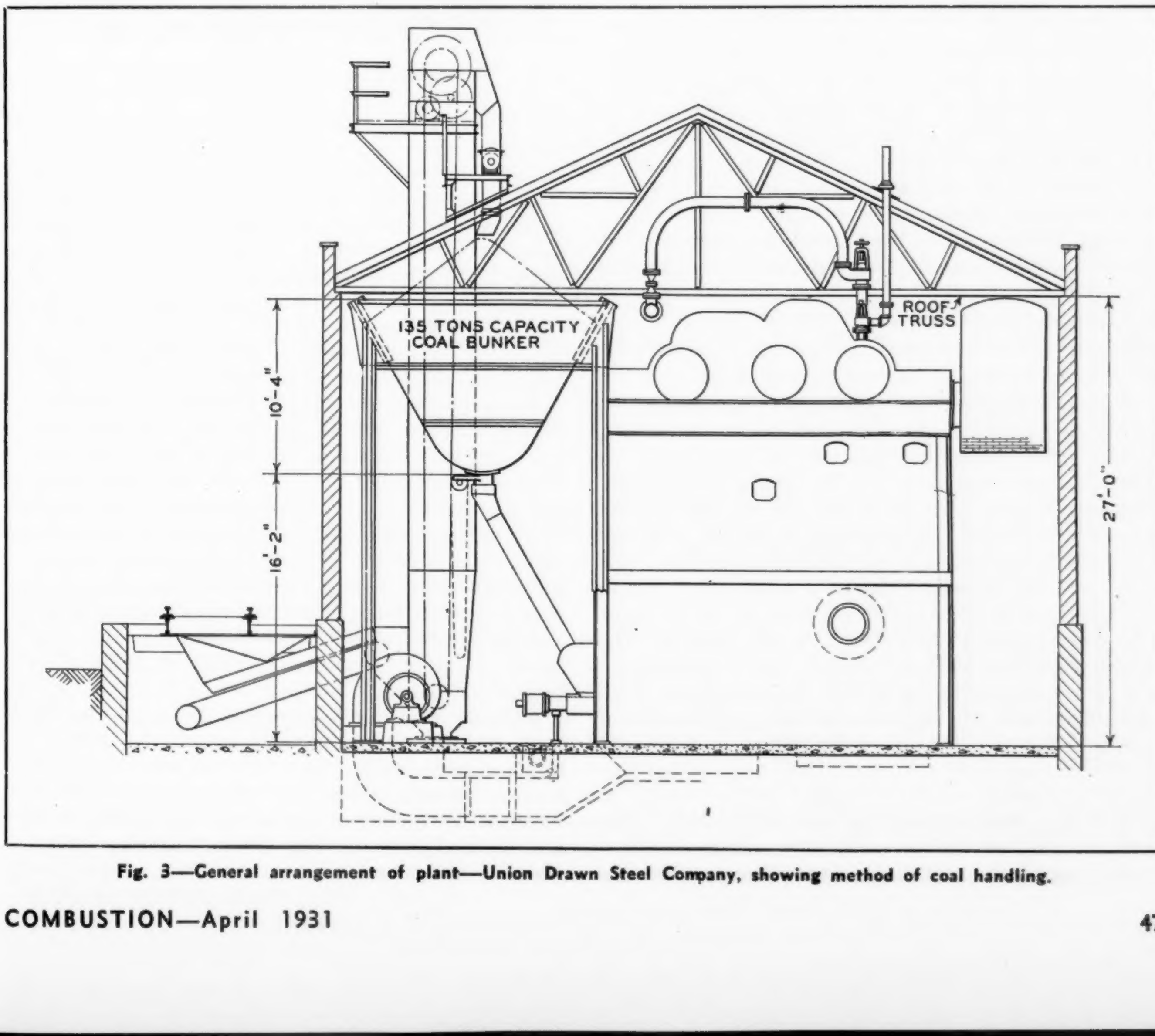


Fig. 3—General arrangement of plant—Union Drawn Steel Company, showing method of coal handling.

freezes and is difficult to open. Steam coils or steam jets in the tank and other methods of keeping the gate mechanism from freezing have been used with some success. Some prefer a flat sliding gate. A hollow tile tank with a flat or steep hopper bottom serves the purpose as well as any, or a sectional cast-iron tank may be used. These are sometimes built with a single sloping bottom and side discharge. Where, for structural reasons, a lighter tank is required it may be made of steel plate and lined with a thin coating of concrete. This has proved very effective in several instances. Poke holes located in the hopper bottom permit the entrance of a bar for breaking up the ash when it packs, and occasionally a mechanical agitator is installed. However, if the gate opening is large enough it will usually empty itself when opened. A large opening is essential. The capacity should be about 50 to 60 tons to allow for some excess over one railroad car in case one is not immediately available. It should be drained to get rid of as much water as possible. The sliding type gate or the clam shell are not the only ones meriting consideration and there are others which may be preferred, but it is well to bear in mind that the greatest difficulty with these storage systems is due to the fine ash packing and freezing in the tank and the consequent difficulty of removal rather than the actual moving of the ash in the conveyor system. This difficulty, however, is usually given the least consideration.

To eliminate some of the inherent difficulties of the steam jet conveyor, certain fundamental changes in design have been brought out. They may be grouped under the vacuum system, the outstanding feature being that the steam does not come into contact with the ashes and therefore the ash is delivered to the tank dry and will minimize the packing or freezing in the ash tank. A steam ejector at the discharge end of the conveyor produces the required vacuum. The wear and tear is also lessened to some extent. This is a very important item and this system is worthy of serious consideration.

For the larger station employing a basement, the boiler furnace is built with a hopper bottom and heavy gates discharge the ash into a small car which empties into a skip hoist. An overhead tank receives the ash from the skip hoist or elevator and discharges it into railroad cars or trucks. Where the conditions warrant such an installation, this form of ash removal meets a wide application and its operation is both economical and simple. The chief factor in this design is the tunnel. The height should be such that a man can walk through it without danger to his scalp. Some form of ventilation should be supplied and it must be easy of access. The ash hopper under the furnace should be of such capacity that it will not require too frequent emptying and if possible hold enough to permit ash removal during one shift only. The form of gate should be carefully analyzed so that it will stand up under the rough usage which it receives. An ash tunnel of this character serving six 600 hp. boilers is shown in Fig. 4.

The above analysis applies to the usual run of small boiler plants and is to be considered only in that light. There are other excellent forms of ash removal to be found in special cases, but they are more pertinent to the larger installations. The last newcomer in this field is the "Hydrojet" which has many very desirable features. It is totally enclosed, preventing the escape of dust and ashes, is easily operated, and is ideal where a nearby fill can utilize the ashes to advantage. When the quantity of ash to be handled warrants the investment, this is an excellent system and is cutting into the older forms at a very rapid rate.

Feedwater Regulation: Every boiler should be equipped with a feed-water regulator and every boiler feed pump should have a pump governor. Maintenance of the correct water level in the boiler at all times and proper regulation for increase or decrease of load requires no argument. The cost of a regulator is so low that there is little excuse for trusting the firemen with maintaining the correct water level, at the best a difficult thing to do manually. With uniform load, a continuous rate of feed is desirable but with a swinging load slight variations in water level are desirable so as to store up heat energy through a higher level at the lighter loads.

Fig. 4—Ash tunnel in plant of Follansbee Bros. Company.

A number of excellent feedwater regulators are on the market and the choice may be confined to the particular experience or prejudice of the owner. The thermostatic tube type has the advantage of extreme simplicity requiring no floats and employing simple mechanical connections. It is installed entirely outside the boiler and is almost foolproof. The regulation from zero to full opening is all that could be desired. The regulating valve must be designed with care but its operation is simple as is its connection through a system of levers to the thermostatic tube.

Another regulator operating through the medium of heat difference and known as a thermohydraulic regulator has certain inherent advantages. The operating medium is the difference in temperature between the steam in an inner tube and the water in an outer or surrounding tube, the quantity of steam in the inner tube varying with

the water level in the boiler drum. The pressure set up by the water vaporizing in the outer tube is communicated to a sylphon bellows which acts as a motor on the balanced boiler feed valve. The motor or bellows is connected to the pressure generating device by a copper tube and may therefore be located anywhere in the boiler feed line. This is a decided advantage in certain layouts.

Some operators prefer a direct acting regulator employing float control. In this type of regulator, change in the rate of flow is instantly responsive to change in water level being caused directly by it. This type preceded all others but met with much difficulty through faulty design of floats which frequently collapsed, exterior stuffing boxes which were difficult to keep properly packed, etc. The present designs have remedied these ailments through the use of open type non-collapsible floats, valve chambers adjacent to the motor chamber and therefore requiring no stuffing boxes or packing, and other improvements.

The float type is not so susceptible to flexibility of installation since the regulator must be placed on a level with the water in the boiler drum and the feed line must therefore be carried up to the valve chamber which is usually bolted to the regulator. The thermostatic tube type is somewhat more flexible in this respect the regulating valve being removed some distance from the tube and operated through a lever system. The thermo-hydraulic regulator has the advantage that the control valve may be placed in a position most advantageous to the piping layout and any reasonable distance from the boiler drum. The operation of the two latter types involves a certain lag which is desirable under a surging load because the higher water level at low loads stores heat which becomes available with decreasing water level at the higher load. The float type has the least lag and is preferred by some operators.

The feed valve of all these regulators is usually of the fully balanced type, with multiple V shaped ports so as to allow for a perceptible movement of the valve when feeding at low ratings and is designed to give certain desirable flow characteristics and reduce wire drawing at these low ratings.

Water Treatment: Volumes have been written on boiler feed water analysis and treatment. Probably no branch of the power plant field has been exploited to such an extent. One is justified in showing skepticism of a new system or boiler compound. No two feed waters are identical in their makeup and each requires special consideration. This condition, however, is frequently stressed beyond the elastic limit and wildest claims made for a new chemical or device. It is best to give consideration to the product offered by a company of known reputation. Boiler feed waters vary in their mineral salt content, both in kind and quantity. Some require but simple treatment while others demand much more elaborate treatment. With low ratings and fairly good water it is possible to operate without water softening and the use of a tube cleaner at frequent intervals removes the slight scale formed, but with bad water and high ratings it is impossible to operate without purification. The treatment may be broadly divided into two parts; external, in which the water is treated before entering the boiler and internal, in which a chemical reagent is fed in with the boiler water. The latter forms by far the larger class but undoubtedly the former is the preferable method. The boiler is a steam generator and not a water treating tank; but in many instances the cost of a water purification system is commercially prohibitive and therefore if the quantity of scale forming matter in the water is comparatively low, water treating compounds may be used to advantage.

Most waters are susceptible to some form of lime and soda treatment. This forms the basis for treating the water both in the boiler and externally. Another external treatment employs lime barium carbonate. The system may be continuous or intermittent and employ the cold or hot process. In the hot process system, advantage is taken of the available heat in the exhaust steam. The chemical reactions are more rapid and complete in hot water and due to this greater activity a smaller excess of softening chemical is required than with cold water. This reduction in the excess of reagent reduces the tendency to foaming and priming. Another feature in favor of the hot process softener is the actual contact of the finely divided water with the steam during the heating process, resulting in driving off the air and other non-condensible gases. This does not occur in cold process softeners.

Internal treatment also employs other chemical compounds which act as reagents or coagulants to assist or hasten the reaction. One of these is sodium aluminate. The water is tested at frequent intervals, either by the engineer in charge or at some laboratory, and a certain quantity of the chemical compound is prescribed. In these plants the water is treated mostly according to the ideas of the operating engineer. It is not perfect and the tubes must be turbined occasionally, the frequency depending on the judgment of the operator and the variability of the water. Perfect boiler feedwater is a rarity but for the greater number of very small plants internal treatment permits operation at fair ratings with a minimum of cost and cleaning.

Another class of boiler water treatments comes under the heading of colloidal treatments. In the chemical treatment of water, a chemical reaction occurs which substitutes one compound for another but in the colloidal treatment the action is purely physical and no chemical reactions are involved. Since this is the case, chemical analysis of the feedwater is not essential beyond the necessity of determining upon an adequate quantity of the colloid and this is one of the arguments presented in its favor. The colloid being vegetable in origin there are several which may be used, flaxseed and sugar beet being probably amongst the best known. Colloidal treatment is being used to

some extent and its merits are worthy of investigation.

Fitting in between the simple internal treatment and the more extensive external lime and soda processes are the several zeolite systems which may fit into the picture. In these systems a natural or artificial sand termed zeolite is used. It has the property of extracting from the raw feed water its scale forming matter with which it becomes coated to the point of saturation. At this juncture, the feed is shut off and the sand "regenerated" by a counter flow of salt water which removes the scale forming impurities and washes them into the sewer, the zeolite being used over and over. The zeolite system is easy to operate, is comparatively inexpensive and where the water does not contain appreciable quantities of acid it probably fills the requirements for the medium sized boiler plant as well as any other water treating system. This type is quite popular in the districts where the acid content is low but is not so successful where it is high. It should not be installed in plants of the latter sort. Where the zeolite system is used and where there is a slight amount of acid in the water it is found advantageous to shut off the purification plant for a day at certain intervals and allow the boiler to become coated with a slight deposit of scale. This adds a protective coating and prevents pitting of the boiler surfaces. The intervals will be decided by the nature of the water, but may be anywhere from one to two weeks. Another method is to continually pass a small quantity of raw water in with the softened water. This may be proportioned to suit by inserting a small orifice of the correct size in the raw water discharge line to the boiler feed pump. The zeolite becomes inactive when its surface is covered with the scale-forming matter of foreign material such as clay or sand. Where the latter is in great quantity, the raw water should first be passed through a filter to extract the insoluble impurities.

In the purchase of a zeolite softener, the specifications should be closely examined for it will frequently be found that the prices for a given capacity of softener vary considerably. The zeolite tank will, in some cases, be smaller in diameter but of greater depth and while it will therefore contain the same cubic content of the active medium the velocity of flow may be too great and consequently some of the zeolite carry over into the boiler feed. The average flow should not be more than 3 to 4 g.p.m. per sq. ft. of area.

The normal capacity may be the same for several softeners but the ability to take care of maximum conditions for a given length of time will vary with the size of the softener. The total quantity of water that can be softened between regenerations is important.

Instruments and Control Apparatus: As one steps into the large modern boiler house, he is confronted with an instrument board with individually mounted instruments of various sorts analagous to the switchboard in the generator room. This is a more recent development but an entirely logical one. The advent of pulverized fuel hastened its adoption. Automatic control of boiler and stoker has been developed to a high state of perfection and the work of the operator consists largely in seeing that the control apparatus for the proportioning of air and fuel is functioning properly and that the necessary changes are made to accommodate the load and fuel bed. The mechanism involved is quite elaborate and has no place in the small station. However, certain instruments are not only desirable in the small station but of considerable value to the operator. The steam pressure gage comes first and next to this, the draft gage. The draft gage should indicate the pressure in the wind box, draft over the fire, and the draft in the last pass, and, in the case of chain grate stokers with zoned air supply, it may have additional readings indicating the pressure in the wind boxes. The writer prefers the direct indicating type of pressure gage rather than the inclined gage. The pointers are easy to read and it appeals more strongly to the operator. For all purposes, other than test work, the direct reading type is sufficiently accurate. Following these is the steam flow meter. There is no doubt that a meter indicating the boiler load results in a certain elevation of the boiler room standard. It places the fireman on a higher plane. This is particularly true of the very small boiler plants where the atmosphere savors but of the shovelling of coal and ash. With the exception of but a very few plants, it is also productive of economic gain. Frequently, peaks on the load chart can be ironed out by a study of the causes producing them resulting in a more uniform load and better operating conditions. The steam flow meter hardly needs any apology but, peculiarly, it is considered under the classification of luxuries rather than of necessities. This statement holds only for the small plant.

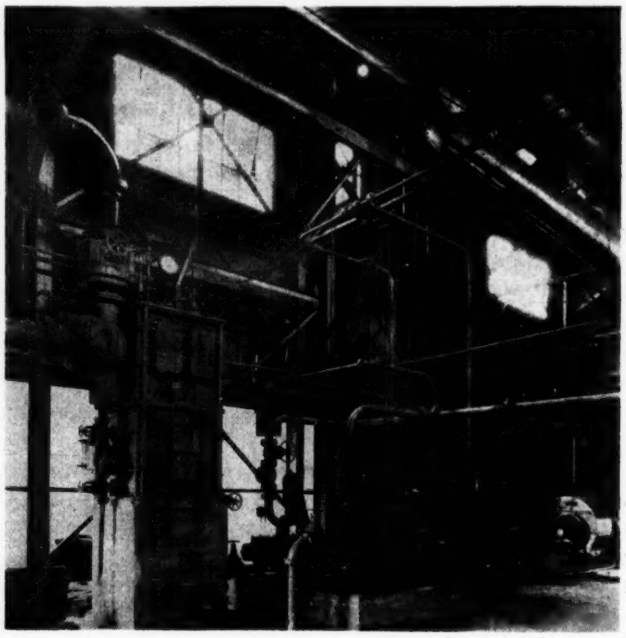


Fig. 5—Partial view of boiler room of Pittsburgh Spring & Steel Company showing forced draft fan and long piping bends.

Many types are on the market, most of them indicating, recording and integrating in one instrument. Some are suitable for mounting on the boiler or in close proximity to it while others may be installed at any distance. In general, a meter indicating the load in horsepower and recording the steam flow in pounds per hour is sufficient for the purpose. Where process steam is used, integration may be added and a record made available for the total steam consumed by any department. It may be desirable to install a number of indicating and recording meters where individual records of several departments are of value.

One form of meter adds the temperature of the flue gas and a special pointer indicates the air flow. The latter pointer can be adjusted so that its travel is in synchronism with the load. It, therefore, forms a basis of proportioning the quantity of air so as to result in a predetermined percentage of CO_2. This meter is an excellent guide for the fireman but somewhat more expensive than others. The type of meter selected and the functions it should include will depend upon the nature of the load to be served. No definite guide can be indicated but an analysis of the conditions in each case will suggest the best type for the purpose.

Control apparatus for holding the boiler pressure uniform is fairly well established and the steam pressure regulator is found in practically every plant. Its function is to keep the pressure in the main header at a constant value. They all embody a differential mechanism acting upon two sides of a diaphragm or piston, steam or water on one side and a spring or weight on the other. The movement of the diaphragm due to pressure changes in the steam header is conveyed to a pilot valve which in turn admits water pressure to the regulator controlling the speed of the steam turbine or motor driving the draft fan, thus varying the fan speed and draft with the change of load. In some cases, the mechanism is also hooked up to the damper in the boiler outlet under the guise of a damper regulator. Some operators prefer automatic damper regulation while others prefer to regulate by hand. There is no divided opinion, however, on the question of the necessity for the steam pressure regulator. Its position is firmly entrenched.

Other instruments may be added to the plant as the individual requirements dictate. The above are important and necessary. Beyond these each case is a law unto itself. Some plants consider a CO_2 recorder a necessity while in others a simple orsat testing set is found sufficient. It is easy to be carried away by enthusiasm and load the plant with a lot of auxiliary apparatus which is not without merit but which the conditions do not demand and which can not pay dividends. Apparatus of this sort may be found in almost every plant; material bought, used for a short time, and then abandoned. The purchase of this class of equipment should be given careful thought. No hard and fast rules can be laid down. Instruments which are actually used pay dividends in some form but those which are bought and abandoned become an eyesore.

Piping: An outstanding feature of the older plants was the maze of steam and water piping leading in all directions and which had

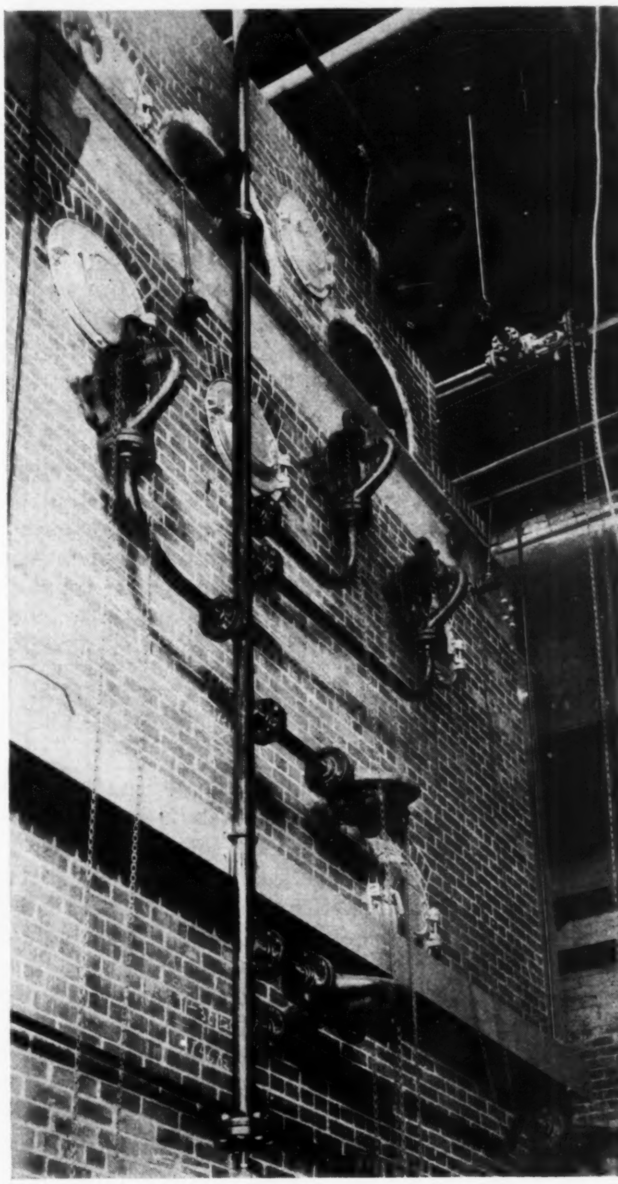


Fig. 6—View of soot blower piping showing welded necks and long bends.

grown up like Topsy. Short bends and many fittings, mostly screwed, were in order; this resulted in excessive pipe friction and many leaking joints. Present day practice calls for long bends and Van Stone joints with flanges for all pipe over 2 in. Where a number of connections are to be taken off from one header, welded outlets or necks save many joints and are less expensive than fittings. With the higher pressures and temperatures, long bends leading from the boiler outlet to the main headers allow for expansion and make for a tight piping system.

The boiler feed lines should be treated in the

(*Continued on page 56*)

Combustion Characteristics of Blast Furnace Gas

By B. J. CROSS

BLAST furnace gas is a "lean" fuel and cannot be economically stored. Its use as a boiler fuel is limited to the vicinity of blast furnaces and it is used almost exclusively by steel plants. The fuel requirements of steel plants for steam generation are usually in excess of the supply of blast furnace gas available and it is therefore common practice to supplement the supply of blast furnace gas with other fuel, usually coal. Moreover, due to the cyclic operation of blast furnaces, the supply of gas even when adequate is not continuous and the supplementary fuel must be used during periods of deficient gas supply. Due to similar furnace design requirements, coal in powdered form or oil is best suited to supplement the supply of blast furnace gas. The choice between coal and oil will depend upon relative price and also upon the extent that the supplementary fuel will be used.

The amount of gas made per ton of iron will vary somewhat with the operation of the furnace. The amount of gas in pounds per pound of carbon in the gas may be computed from the following expression:

$$\text{Gas per pound of carbon} = \frac{44CO_2 + 28N_2 + 28CO + 2H_2}{12CO_2 + 12CO}$$

Carbon goes into the blast furnace in the coke and limestone charged. The carbon in the limestone can be accounted for by the carbon in the iron and in the dust in the gas. The carbon in the gas may be assumed, with but small error, to come entirely from the carbon in the coke charged. The gas per pound of coke may therefore be found by multiplying the gas per pound of carbon by the weight of carbon per pound of coke.

An average figure for the amount of gas produced by a blast furnace is 150,000 cu. ft. per ton of iron or about 160,000 cu. ft. per ton of coke charged. About 10 per cent of this amount is lost through leakage and about 30 per cent is required to preheat the blast. The amount of gas available for fuel is about 90,000 to 95,000 cu. ft. per ton of iron or about 100,000 cu. ft. per ton of coke charged.

The combustible constituents of blast furnace gas consist of carbon monoxide (CO), hydrogen (H_2) and in small amount, methane (CH_4). The combustion reactions for these gases are:

$$2CO\ (56) + O_2\ (32) = 2CO_2\ (88)$$
$$2H_2\ (4) + O_2\ (32) = 2H_2O\ (36)$$
$$CH_4\ (16) + 2O_2\ (64) = CO_2\ (44) + 2H_2O\ (36)$$

Thus, two volumes of CO require one volume of oxygen or 4.76 volumes of air for its combustion. The figures in parenthesis are the molecular weights times the number of molecules and represent the proportion by weight of the substances. Hydrogen and carbon monoxide require 2.38 cu. ft. of air per cu. ft. Methane requires 9.52 cu. ft. of air per lb. of gas. The heat value of CO is 323.5, hydrogen 326.2 and of methane 1009 B.t.u. per cu. ft. at 60 deg. fahr.

Blast furnace gas is sometimes used at temperatures considerably higher than that of the air used for combustion. In these cases it is often convenient to consider the gas to be at the same temperature as the air and to correct the heat value by the sensible heat between its actual temperature and the air temperature. A specific heat of .24 may be used for this purpose.

A representative analysis of blast furnace gas, per cent by volume, dry basis, is given in Table II.

Washed blast furnace gas may be considered to contain moisture equivalent to saturation at its temperature. The dust content will vary from 5 to 10 grains for unwashed gas. The dust content of washed gas may be reduced to .3 to .5 grains per cu. ft.

TABLE I.

	a per cent by volume	b molecular weight	c = a × b proportion by weight	d per cent by weight	Ultimate Analysis per cent C	H_2	O_2	N_2
Carbon dioxide CO_2	10.0	44	440	15.3	4.2		11.1	
Carbon monoxide CO	27.5	28	770	26.7	11.45		15.25	
Hydrogen H_2	3.0	2	6	.2		.2		
Oxygen O_2	1.0	32	32	1.1			1.1	
Methane CH_4	.3	16	5	.2	.15	.05		
Nitrogen N_2	58.2	28	1630	56.50				56.15
Total	100.0		2883	100.00	15.80	.25	27.45	56.15

Average molecular weight = 28.83 — Cu. ft. per lb. at 60 deg. fahr. = 379.5 divided by 28.83 = 13.16
B.t.u. per cu. ft. at 60 deg. fahr. = 102 — B.t.u. per lb. = 1342

The analysis by volume may be converted into analysis by weight and the ultimate analysis may be calculated as shown in Table I. Each constituent is multipled by its molecular or relative weight. The product gives the proportion by weight of the constituent. The compound may then be divided into its elements according to the atomic weights of each element. From the ultimate analysis so calculated, the combustion characteristics of blast furnace gas may be computed from standard equations for solid fuels.

When gas and coal are burned together, a composite ultimate analysis should be computed using the proportions by weight of each fuel burned.

The combustion characteristics of blast furnace gas of the analysis given are shown in chart below.

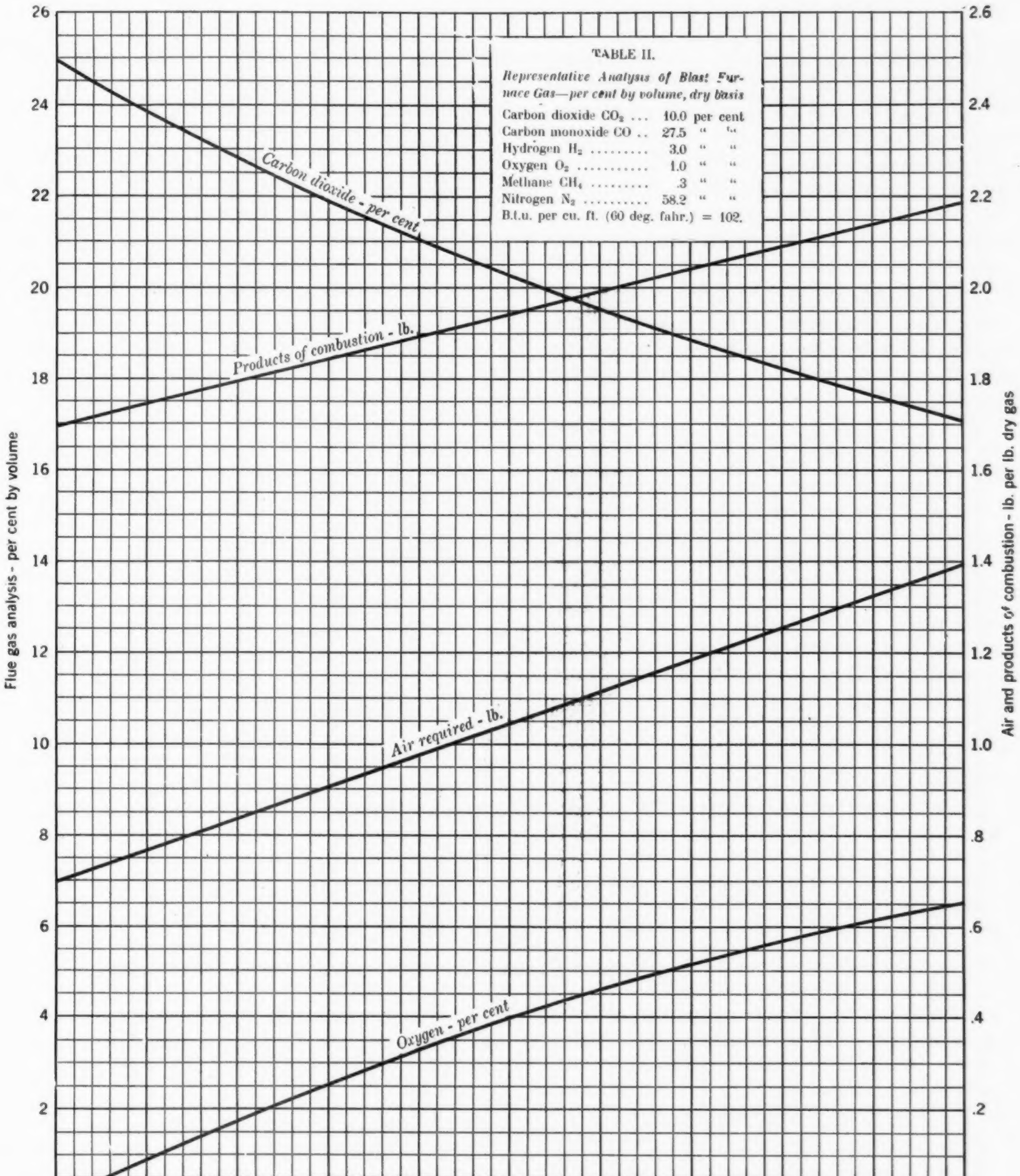


TABLE II.

Representative Analysis of Blast Furnace Gas—per cent by volume, dry basis

Carbon dioxide CO_2 ...	10.0	per cent
Carbon monoxide CO ..	27.5	" "
Hydrogen H_2	3.0	" "
Oxygen O_2	1.0	" "
Methane CH_4	.3	" "
Nitrogen N_2	58.2	" "

B.t.u. per cu. ft. (60 deg. fahr.) = 102.

CHART SHOWING COMBUSTION CHARACTERISTICS OF A REPRESENTATIVE BLAST FURNACE GAS

No. 21 of a series of charts for the graphical solution of steam plant problems.

Two Important Fuel Investigations at Battelle Memorial Institute

BATTELLE Memorial Institute, cooperatively with the Engineering Experiment Station of Ohio State University, has been conducting semi-commercial experiments on the carbonization process as proposed by White at the International Fuel Conference in Pittsburgh in 1926. This process consists in allowing coarsely powdered coal to fall through an externally heated tube or retort so that the particles are carbonized during the fall.

The by-products are withdrawn from the retort through the usual ascension pipe or offtake and the carbonized residue is removed from the bottom of the retort through a water seal or by other suitable means.

White's work consisted in laboratory experiments, using nichrome tubes as retorts. These were 2 to 3 in. in dia. and 27 to 84 in. long and heated electrically. He treated Elkhorn and Illinois coals and South Dakota lignite in various sizes from 14 to 100 mesh and obtained data on the residue and gas but none on the other by-products.

The Engineering Experiment Station at Ohio State University has a standard one-ton U.G.I. vertical retort equipped with condensing, scrubbing, and other necessary by-product apparatus, which is available for experimental work. This equipment was remodeled to make it suitable for tests on this process by providing continuous feeding and discharging features and adding an electrostatic dust precipitation chamber. This latter was for removal of dust carried out of the retort in the gas stream and was installed adjacent to the retort so that precipitation occurred before the condensation of the tar vapors.

Tests were made on coals from Ohio, West Virginia, and Illinois. Data were obtained on the yields of residue, gas, tar, light oil and ammonia. The usual analytical determinations are being made on these products. It was found that only the weakly caking coals could be used without sticking to the retort wall and clogging the free space. Higher temperature aided in preventing this trouble, but strongly caking coals invariably clogged the retort within a short time. Thus the process is limited in its use to a few coals in Ohio and is probably unsuited to any of the remaining coals in the eastern province. The Illinois coals tried were satisfactory and in all probability the remaining Illinois coals are suitable.

The residue obtained from these tests is essentially of the same size as the coal fed, that is, coarsely granular. Tests will be made on its suitability as a pulverized fuel as this is its most logical use.

The work is still in progress.

Investigation of Process of Combustion of Pulverized Coal

Pulverized coal as a fuel for boiler furnaces, cement kilns, and metallurgical furnaces has developed to its present important position in a relatively short period. Although progress has been rapid through the accumulated experience of designers and operators of equipment, and although the efficiency with which pulverized coal may be burned for steam generation, for example, is so high that no further great improvement may be expected, yet the mechanism of the process of combustion is not thoroughly understood. A study which would bring about a complete understanding of the process of combustion should insure more rapid progress in the field because it would answer many questions on which engineers are not now agreed in their answers, such as: (1) The proper fineness to which coal should be ground, (2) the effect of moisture content of the fuel, (3) the relation of the type of coal to the process of combustion, (4) the effect of preheated air, (5) the proper design of the burner and furnace, and (6) the best operating temperature.

Recognizing these facts, Battelle Memorial Institute has undertaken an investigation of the combustion of pulverized fuel.

Complete equipment for the investigation has been purchased and installed; it consists of a rotary drier, a pulverizing mill, an air classifier to govern the size of the coal, a storage bin, weighing tank, scales, feeder, fans and furnace. The equipment is designed for rates of drying, grinding, and burning up to 500 lb. per hr. The furnace consists of a cylindrical, horizontal, refractory-lined steel shell, 3½ ft. inside dia. and 15 ft. long. The entire set up is therefore of such size that it simulates actual furnace conditions.

Special attention was given to the weighing equipment to know accurately the rules of firing, and the rate of air supply is carefully measured. Numerous sampling and observation ports are provided about the furnace, through which the process of combustion will be studied by sampling and analyzing the gases, the dust carried in the gases, and by measuring temperatures.

Several preliminary tests have been run to work out a satisfactory burner design that can be used with a variety of types of coal.

NEWS

Pertinent Items of Men and Affairs

Foster Wheeler Acquires Connelly Boiler Company

Through the acquisition of the D. Connelly Boiler Company, Cleveland, Ohio, the Foster Wheeler Corporation, New York, has entered the field of boiler manufacture.

The Connelly Company has been building boilers for more than fifty years, and many types have been developed. Foster Wheeler Corporation has announced that the following units are to be produced: "forged steel, sectional header cross drum boilers; four drum and three drum bent tube boilers; three drum 'low head' bent tube and two drum bent tube boilers. For marine service there will be offered, as in the past, cross drum steam generators of both box header and sectional header designs; three drum 'A' type and two drum low head units."

The possession of a fully equipped boiler shop has the further advantage of enabling Foster Wheeler to meet all of its requirements for heater and evaporator shells as well as for fractionating and stabilizer towers, used extensively in its petroleum refining and gasoline recovery plants.

•

The Edward Valve & Manufacturing Company, manufacturer of valves for high pressures and high temperatures, has appointed Bell & Eiss, Inc., 459 N. W. National Life Building, Minneapolis, Minn., as representative in the territory tributary to the Twin Cities.

•

General Refractories Company, Philadelphia, has appointed the Davis Coal and Supply Company, Reading, Pa., as local distributors.

•

Girtanner Engineering Corporation, 30 Church St., New York City, manufacturer of ash conveyors, has become a part of the Wilbur G. Hudson Corporation, contracting engineers specializing in coal handling systems and located at 30 Church Street, New York. The Girtanner Engineering Corporation will continue to operate under its own name as heretofore. Officers of the new combination are W. W. Burden, president; Alexander Girtanner, vice-president and general manager; and J. A. Robinson, chief engineer. The same personnel has been retained and with the addition of the engineering and sales staff of the Hudson company, the Girtanner Corporation plans to broaden its activities to include new lines of equipment.

Gifford-Wood Merges C. W. Hunt Company

Gifford-Wood Co., Hudson, N. Y., manufacturer of elevating and conveying equipment, has absorbed the C. W. Hunt Co., Inc., West New Brighton, Staten Island, N. Y. The Gifford-Wood Co. will manufacture and sell the complete line of equipment formerly produced by the C. W. Hunt Co., Inc., and will operate that company as a division of the Gifford-Wood Co. Manufacturing has been transferred to the main plant of the Gifford-Wood Co., at Hudson, N. Y. Sales and service will be handled through the Gifford-Wood sales organization at its regional offices in the Graybar Building, New York, and at 565 West Washington Street, Chicago.

•

F. R. Wadleigh and E. L. Bailey have joined in the practice of consulting mining and fuel engineering, with offices in the Southern Building, Washington, D. C.

•

J. Roy Tanner has been elected president of the Pittsburgh Valve, Foundry and Construction Co., Pittsburgh. Mr. Tanner is well-known in the valve, piping and foundry industry, having entered the employ of the Pittsburgh company in 1901 and serving as its vice-president and general manager since 1911.

•

United Conveyor Corporation, Old Colony Building, Chicago, manufacturer of Nuveyor and Steamatic ash and soot conveyor systems, has announced the formation of a Canadian associated company, United Conveyor Corporation of Canada, Ltd., 7 Queen Street East, Toronto, Ont.

•

Northern Equipment Company, Erie, Pa., manufacturer of Copes Feed Water Regulators, Differential Valves and Pump Governors, announces the appointment of the following representatives:

The Economy Equipment Company, 301 Buder Building, St. Louis, Mo.

Jos. W. Eshelman, 1220 Webb-Crawford Building, Birmingham, Ala.

Bell & Eiss, Inc., 459 N. W. National Life Building, Minneapolis, Minn.

•

Illinois Testing Laboratories, Inc., 141 West Austin Avenue, Chicago, has appointed Ernest H. DuVivier, 30 Church Street, New York, its representative in Metropolitan New York and Northern New Jersey and F. W. Fernald, 335 Fifth Avenue, Pittsburgh, as its representative in Western Pennsylvania and West Virginia for its line of Pyrometers, Resistance Thermometers and other measuring instruments for industrial uses.

Considerations in the Design of the Small Boiler Plant

(Continued from page 51)

same manner as the steam lines and it is well to have the hot water line of copper or brass. Fig. 5 is a fair example of short lines and long radius bends between the boiler feed pumps and the heater.

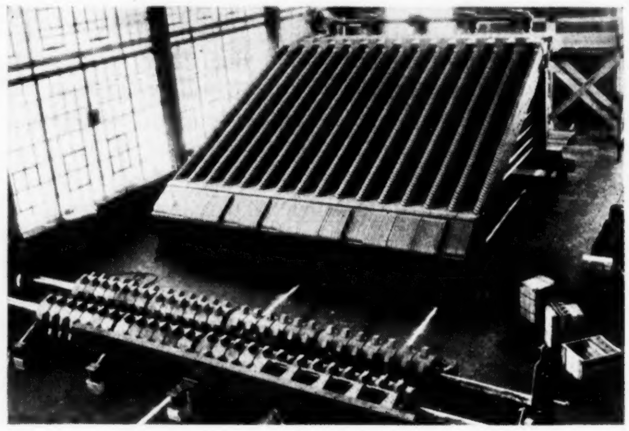
The ordinary soot blower system consists of a supply pipe and branches to the blower heads necessitating a large number of fittings which frequently become leaky due to the extreme temperature difference between the periods when the blower is in operation and when it is inactive. An excellent method of connection is made up of a central leg with welded necks and long radius bends to the blower heads. This eliminates many joints and allows for expansion. Note this design in Fig. 6. The lines should be given plenty of drop for drainage.

Each plant will have its own pipe system and arrangement but a little careful thought in the design of the piping will probably eliminate more Sunday work than is necesary in any other portion of the plant.

Efficiency: The term efficiency is a misused word when applied to the average power plant. The small boiler room is not likely to have an operating staff comparable with that of the larger plants, and comparable economies should not be expected. The size of units and the complex detail equipment characteristic of large plants represents an expenditure which is prohibitive for the small station. The load may be fluctuating in character which does not permit the best operating schedules. It is well to bear this in mind and design the small plant for fair efficiency over a wide range rather than go to extremes in the matter of auxiliary equipment, instruments and labor saving devices in order to secure maximum results. The cost of the plant is thereby kept down to a minimum. The average operator can handle it with fair economy and with reasonable maintenance expense. It is not expected that in the small station boiler efficiencies of 80 per cent will be reached nor that a kilowatt will be produced on 13,000 B.t.u., but if the boiler room is operated with fair fuel economy, low maintenance and a minimum of attendance and is not burdened with excessive over-head due to high construction costs, it will not only pay dividends but present a very favorable comparison with the large central station with its phenomenal combustion and generating efficiency but which labors under the handicap of transmitting steam over comparatively long distances for heating or process work. The total overall efficiency of the small plant which can utilize low pressure steam manufacturing electrical energy as a by-product need not reach the highest attainable efficiencies of the large station to successfully compete with it.

Largest Stokers Nearing Completion

The photograph below shows one of the 8 Taylor Multiple Retort Stokers being built for the Brooklyn Edison Company at the plant of the American Engineering Company. These stokers are 15 retorts wide by 69 tuyeres long, and are the largest Taylor Stokers ever built. The overall dimensions are approximately 26 ft. wide by 27 ft. long. One of these stokers will be installed under each of the 8 Combustion Engineering Bent-Tube Boilers which are now being erected at the Hudson Avenue Station of the Brooklyn Edison Company.



The design of these stokers involves a radical departure from the ordinary means of actuating the secondary feed rams. Each secondary ram or pusher rod has been brought out to the front of the stoker where the stroke can be individually adjusted.

One of the principal considerations in design was the necessity of providing for expansion and contraction of the fuel carrying structure with changes in temperature. The lower end of the stoker rests free on rollers while the upper end carries into a hinge joint. If the stoker expands it moves out upon the rollers and, of course, about the hinge joint. Transverse expansion across the furnace is taken care of within each retort so that there is actually no increase or decrease in the width of the stoker with a change in temperature.

The crusher rolls and the drive of the Brooklyn Edison stokers will be powered by a Hele-Shaw transmission, consisting of hydraulic pump and motor, direct connected, and a hydraulic motor on the speed shaft of the power box. The rate of discharge from hydraulic pump to hydraulic motor can be varied within a range of 20 to 1 by moving the rotating member off center.

The hydraulic stoker motor is designed on the same principles as the pump except that since it has a constant displacement, its rotation varies directly with the rate of flow from the pump. Any speed between zero and maximum of the pump will be available, providing a very flexible drive.

At maximum rating the Brooklyn Edison Stokers will be capable of burning 28.3 tons of coal an hour, almost 2 tons per retort per hour.

NEW EQUIPMENT

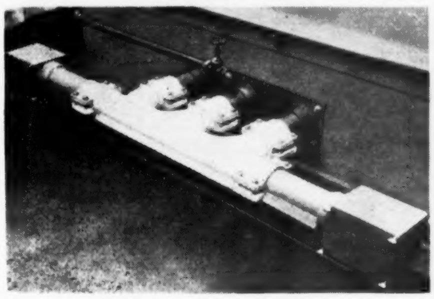
of interest to steam plant Engineers

New Smoke Recorder

The Leeds & Northrup Company, Philadelphia, recently introduced a new device for indicating and recording smoke density.

An L & N Smoke Recording Installation consists of a measuring chamber at the stack or breeching, a recorder at any convenient location and an indicator at the boiler.

The measuring chamber, through which the smoke passes, contains a lamp,



at one end, and a specially constructed, temperature compensated thermopile, at the other. Heat radiated from the lamp passes through the smoke-filled chamber and falls on the thermopile. With a constant heat-source in the lamp, the amount of heat falling on the thermopile is inversely proportional to the density of the smoke. The heat from the lamp which reaches the thermopile causes it to generate a voltage. The measurement of this voltage is the measure of the smoke density.

The recorder is a standard L & N Potentiometer Recorder. It measures the voltage of the thermopile and reads directly in per cent smoke density or Ringelmann chart numbers.

The boiler-room indicator is a bank of five lamps. The color of the lamp that is burning instantly tells the fireman the smoke condition in the stack.

The accompanying illustration shows the smoke density measuring chamber attached to a breeching.

Test Water Cooling Coil

The sampling of steam and water at various points in the power cycle has come to be a necessity in modern power plant operation. Samples are taken:

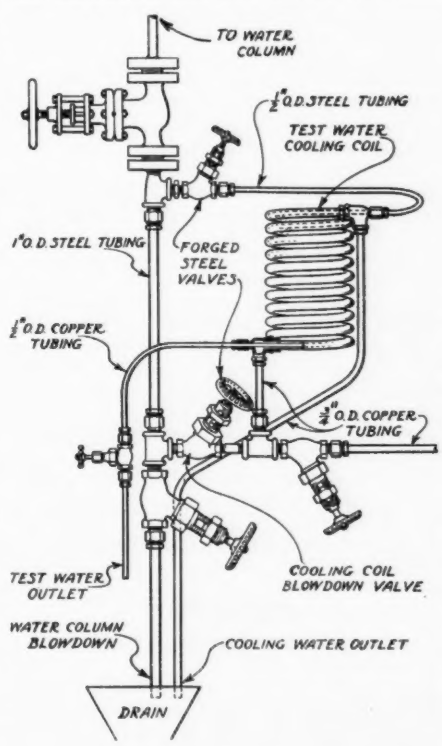
1. To determine quality of water supply.
2. To control the method of treatment for the prevention of corrosion and scale formation.
3. To control boiler concentration.
4. To minimize wet steam, foaming and priming.
5. To detect and measure condenser leakage.

In order to secure representative samples, it is necessary to cool the hot sample to room temperature while still under pressure. If this is not done, the sample will not be representative due to the "flashing" of the water samples drawn off. A neat, compact and highly efficient method of securing representative water samples is now offered by Bailey Meter Company, Cleveland, Ohio, in the Dieform Test Water Cooling Coil.

These coils, which consist of a tube within a tube, are made from copper tubing and Dieform compression fittings. In operation, the hot test sample enters the smaller inner tube at the top while the cooling water enters the outer tube at the side outlet on the bottom. Cooling water completely surrounds the inner tube as it passes upward through the annular space between the tubes to the side outlet at the top. This cooling coil performs at maximum efficiency because of the counter flow principle which tends to equalize the rate of heat transfer throughout the coil. Due to the upward flow in the outer coil, a supply of cooling water always surrounds the inner coil regardless of how slowly water flows through the outer coil.

These coils are used to secure boiler water samples, steam manifold samples, evaporator samples, turbine samples and water samples at boiler feed pumps, feedwater storage tanks and purifiers.

The method of installing the coil for obtaining boiler water samples is shown in the accompanying illustration. The inner tube of the coil is connected to the boiler water column blowdown so that samples of test water may be taken from the blowdown line and cooled to room



temperature before they are released to atmospheric pressure and collected in glass bottles at the test water outlet. A valve in the cooling water supply line makes it possible to vary the flow of cooling water through the coil and thereby control the temperature of the test water sample. The rate of flow of test water is controlled by a forged steel valve in the ½ inch steel tubing which connects the test water cooling coil to the water column blowdown.

Most successful results are obtained by drawing test water samples at the rate of approximately one quart per minute and by taking a total sample of approximately one gallon.

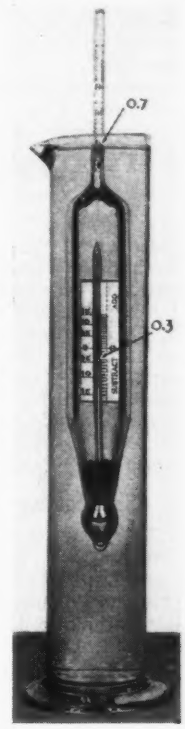
Dieform test water cooling coils are designed for working pressures up to 1500 lb. per sq. in. and may be built specially for higher pressures if desired.

Special Hydrometer for Continuous Blow-off

For a given boiler design and set of boiler operating conditions, there is a maximum saline concentration of boiler water beyond which steam of good quality will not be obtained. It is customary to use a hydrometer to determine this saline concentration, but the hydrometer reading varies with the temperature of the liquid (a change of only 5 deg. fahr. is equivalent to a change in concentration of about 100 grains of salts per gallon). Thus it has been necessary to read temperatures and to make corrections with the aid of complicated tables, or to wait for the temperature of the water sample to reach the exact point for which the hydrometer is calibrated.

To overcome these difficulties, the Permutit Boiler Blow-off Hydrometer has been developed by The Permutit Company, 440 Fourth Avenue, New York. With this hydrometer, temperature corrections are read directly in terms of density.

An integral thermometer, placed in the bulb of the instrument makes it possible for the operator to make the correction readily and instantaneously. This hydrometer is furnished with Permutit Continuous Blow-off Equipment, but may also be purchased separately.



The temperature correction scale reads directly in terms of density correction.

Stem Reading	°Bé	0.7
Subtract correction	°Bé	0.3
Corrected Reading	°Bé	0.4

NEW CATALOGS AND BULLETINS

Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine

Ash Conveyor

The Nuveyor conveyor consists essentially of five units: 1—a special hard iron conveying pipe, 2—an air-tight receiver which incorporates an efficient stage of dust separation, 3—an automatic, air-tight discharge gate, 4—an air washer, 5—an air exhauster. The ash is conveyed through the pipe line by a flow of air created by the air washer. The receiver intercepts the ash, separates it from the air and periodically discharges it to the storage bin. The air washer cleans the dust from the air before it is discharged to the atmosphere. A new bulletin describes this system in detail and shows a number of interesting application arrangements. 20 pages and cover, 8½ x 11—United Conveyor Corporation, Old Colony Building, Chicago, Ill.

Boiler Baffles

The Beco-Turner Baffle is shown in a new folder. Numerous illustrations present the details of construction and methods of installation. A series of interesting line drawings compare Beco-Turner Baffles with the usual type of baffle and emphasize the increase in boiler efficiency due to correct baffle design. Four typical application arrangements covering various types of boilers are also included. 6 pages, 8½ x 11—Boiler Engineering Company, 24 Commerce Street, Newark, N. J.

Circulating Water Treatment

"Eliminating Slime in Condensers by Chlorination" is the title of new technical publication No. 112. Intermittent chlorination for the control and elimination of slime in surface condensers at steam power plants is a new development. It is a logical sequel to the very successful use of chlorine to control troublesome microscopic growths interfering with various processes in the treatment of water. Conditions may vary widely, but the cause is the same—microscopic plant and animal forms come to all waters. When such growths are once attached to condenser tubes, they collect inorganic and organic matter into a gelatinous mass to form slime. The elimination of slime means increased average vacuum and minimum outage for condenser cleaning. The information is comprehensive and well presented. 32 pages and cover, 6 x 9—Wallace and Tiernan Products, Inc., Belleville, N. J.

Damper Regulators

Victor Damper Regulators are hydraulically operated. They maintain the desired pressure in steam boilers by automatically adjusting boiler drafts or dampers. On forced draft boilers, they may be arranged to control the speed of the fans and on stoker-fired units the rate of fuel feed may be automatically controlled. Three types are available: No. 501—for low pressure and vapor heating boilers, No. 502—for medium pressure power boilers, No. 503—for high pressure boilers. The last two types are equipped with a compensating attachment which limits the travel of the control piston and permits the regulator to assume intermediate positions except on extreme pressure variations. Application arrangements and complete specifications are included. 12 pages, 8½ x 11—Atlas Valve Company, 282 South Street, Newark, N. J.

Feedwater Control

A new catalog describes the Copes System of Feedwater Regulation by differential pressure control—the maintenance of the correct pressure drop across the feedwater regulator valve in each individual boiler feed line. This system controls both the feed flow and the differential pressure and assists in increasing the operating efficiency of modern boilers. The booklet is replete with colored charts and diagrams which illustrate the advantages of this method of control. The details of the apparatus are clearly indicated and several application arrangements are presented, together with an impressive list of users. 16 pages and cover, 8½ x 11—Northern Equipment Company, Erie, Pa.

Pressure Gage

Bulletin 1079 describes the new Duragauge which was developed to meet the demand for a rugged, durable and accurate pressure instrument, particularly for use with high pressures and high temperatures. The movement of the Duragauge is Nitralloy—a steel with the hardest surface of any substance known except the diamond. Since the movement is rust-proof, smooth operation is assured permanently. For all pressures of 100 lb. and over, the Duragauge is made with a Bourdon spring which is hot-rolled, special alloy steel. This spring will safely withstand pressure of 500 per cent of the normal working pressure for graduations up to 2000 lb. and for higher pressures, there is a high factor of safety. In the standard wall type gage, the case is of cast iron with smooth surface and hard rubber finish. The accuracy of the Duragauge is ½ of 1 per cent over the entire scale range. All pressure ranges are supplied from 15 lb. to 10,000 lb. 8 pages, 7¾ x 10¾—Consolidated Ashcroft Hancock Company, Bridgeport, Conn.

Pyrometers

Alnor pyrometers are presented in a new bulletin No. 531. The standard temperature ranges are from 0 to 2000 deg. fahr. However, a range from 0 to 3000 deg. fahr. can be provided at extra cost, using rare metal thermo-couples. In addition to the standard line of pyrometers for panel mounting, portable types are also available. 8 pages, 3½ x 6½—Illinois Testing Laboratories, Inc., 141 West Austin Avenue, Chicago.

Steam Flow Meter

An unusually attractive folder presents a strong appeal for the installation of steam flow meters. Specific reference is made to the advantages of the Brown Electric Flow Meter and a series of simple illustrations show the principle of operation and the details of the apparatus. The meter presented is of the indicating, recording and integrating type. It is applicable for measuring steam, water, oil, air or gas. 12 pages, 8½ x 11—Brown Instrument Company, Wayne and Roberts Avenues, Philadelphia, Pa.

Steam Purifiers

Schutte and Koerting Steam Purifiers and Oil Separators are illustrated and described in a new three-color bulletin No. 9-P. The purifiers are of the diffuser type and are built in two designs: the external type for installation outside of the boiler and the internal type for installation in the upper part of the boiler drum. The oil separators are available in three styles: horizontal, vertical upflow and vertical downflow. Application arrangements are shown covering various methods of installing the equipment and tables giving sizes, capacities, dimensions and prices are included. 8 pages, 8 x 11—Schutte and Koerting Company, Philadelphia, Pa.

Storage Bins

Neff and Fry Super-Concrete Stave Storage Bins are presented in a new folder. The concrete staves are made from identical moulds and have the advantages of permanency and durability. They may also be dismantled and re-erected at a different location and as the parts are standardized and interchangeable, they can be used to build a bin of any desired standard height or diameter.

These storage bins can be used for a wide range of materials and are particularly applicable for storing coal, coke and ash. Designs are available which provide for storing two different materials or material of two different sizes in the same bin. 8 pages, 8½ x 11—The Neff and Fry Company, Camden, Ohio.

NOTICE

Manufacturers are requested to send copies of their new catalogs and bulletins for review on this page. Address copies of your new literature to

COMBUSTION

200 Madison Ave., New York

Boiler, Stoker and Pulverized Fuel Equipment Sales

BOILER SALES—January Report

New orders for 598 steel boilers were placed in January, 1931, according to reports submitted to the Bureau of the Census by 74 manufacturers,[1] comprising most of the leading establishments in the industry, as compared with 814 boilers in December, 1930, and 905 boilers in January, 1930.

Month	1930 Number	1930 Square feet	1931 Number	1931 Square feet
January	942	1,081,749	598	576,723
February	873	938,906		
March	977	1,263,709		
April	1,017	1,070,093		
May	1,283	1,329,748		
June	1,360	1,588,553		
July	1,309	1,410,096		
August	1,371	1,356,751		
September	1,254	1,282,388		
October	1,189	* 851,525		
November	777	709,322		
December	814	587,053		
Total (Year)	13,166	*13,469,893		

New Orders, by Kind. Placed in January, 1930—1931

Kind	January, 1930 Number	January, 1930 Square feet	January, 1931 Number	January, 1931 Square feet
Stationary:				
Total	905	884,159	585	563,115
Water tube	78	422,114	62	263,852
Horizontal return tubular	71	92,265	36	50,734
Vertical fire tube	118	37,339	59	15,194
Locomotive (not railway)	10	7,394	7	4,250
Steel heating [2]	504	214,225	355	169,907
Oil country	85	92,180	37	41,460
Self contained portable [3]	28	15,740	22	11,292
Miscellaneous	11	2,902	7	6,426
Marine:				
Total	37	197,590	13	13,608
Water tube	32	195,840	4	5,920
Pipe	..	......	2	2,998
Scotch	2	358	7	4,690
2 and 3 flue	..	......	...	......
Miscellaneous	3	1,392	...	......

[1] 7 of the 81 manufacturers mentioned in the December, 1930, report have gone out of business.
[2] As differentiated from power.
[3] Not including types listed above.
* Revised.

PULVERIZED FUEL EQUIPMENT SALES

New orders for pulverized fuel equipment in January reported to the Bureau of the Census by 11 manufacturers, believed to constitute the entire industry, aggregated 17 mills with a total capacity of 55 tons per hr. compared with 6 mills with a total capacity of 7 tons per hr. in December.

Year and Month	Central System: No. of Pulverizers	Central System: Total Rated capacity in tons of coal per hour	Central System: Total Rated H.P. of boilers equipped	Unit System: No. of Pulverizers	Unit System: Total Rated capacity in tons of coal per hour	Unit System: Total Rated H.P. of boilers equipped
For Installation Under Water-Tube Boilers						
1930						
January	1	6	1,600	52	565	59,742
February	2	20	3,000	29	175	23,305
March	2	50	6,414	16	33	9,995
April	..	...	.....	39	153	38,931
May	3	80	11,360	30	196	22,625
June	1	6	802	15	28	7,146
July	2	22	1,000	12	29	20,424
August	..	...	.....	4	13	1,454
September	..	...	.....	24	112	18,729
October	..	...	.....	10	16	3,499
November	..	...	.....	15	40	7,692
December	..	...	.....	3	5	958
Total (year)	11	184	24,176	249	1,365	214,500
1931						
January	2	30	4,240	9	22	4,334
For Installation Under Fire-Tube Boilers						
1930						
January	..	...	.....	6	35	965
February	..	...	.....	2	13	305
March	..	...	.....	3	3	450
April	..	...	.....	3	3	780
May	..	...	.....	...	....	.....
June	..	...	.....	...	....	.....
July	..	...	.....	...	....	.....
August	..	...	.....	3	3	712
September	..	...	.....	6	3	900
October	..	...	.....	...	....	.....
November	..	...	.....	5	3	641
December	..	...	.....	...	....	.....
Total (year)	..	...	.....	28	63	4,753
1931						
January	..	...	.....	6	3	900

MECHANICAL STOKER SALES

Washington, D. C.—Statistics for January, 1931, on sales of mechanical stokers, based on data furnished the Bureau of the Census by 24 leading manufacturers, are presented in the table below. Owing to the additional number of establishments reporting and the material change in the information given, the figures for January, 1931, are not comparable with the figures for previous months published in the December, 1930, release.

	Total Number Stokers Sold During Month	Total Horsepower Boilers	Total Sq. Ft., Grate Surface	Installed in connection with—Water Tube Boilers: Number	Water Tube Boilers: Horsepower	Fire Tube Boilers: Number	Fire Tube Boilers: Horsepower	Industrial Furnaces: Number	Industrial Furnaces: Sq. Ft. Grate Surface	Other Heating Boilers Household Furnaces: Number	Other Heating Boilers Household Furnaces: Sq. Ft. Grate Surface
Class 1 (Capacity less than 50 lb. per hr.)	212	1,928	668			*236	6,301	*92	852	51	89
Class 2 (Capacity 50 lb. to 300 lb. per hr.)	205	4,413	1,865	*55	21,258					*40	185
Class 3 (Capacity 300 lb. per hr. and over)	180	36,454	6,345			92	15,236	31	660		
Totals	597	42,795	8,878	55	21,258	328	21,537	123	1,512	91	274

* Combined to avoid disclosures of individual operations.